SOUTHWESTERN FORESTS ECOLOGICAL RESTORATION PROJECT

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Southwestern Forests Ecological Restoration Project

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Introduction

Ecological restoration is a promising approach to reversing ecosystem degradation, especially where management is concerned with conservation of native biological diversity. Ecological restoration is defined as "the process of reestablishing to the extent possible the structure, function, and integrity of indigenous ecosystems and the sustaining habitats that they provide" (Society for Ecological Restoration 1993). Ecosystem management policies on National Forest lands are also based on native ecosystem characteristics, recognizing ecological restoration as an important tool to improve ecosystem health in many areas (Kaufmann et al. 1994). Extensive research has been carried out in the Southwest to characterize the natural range of variability in forest ecosystems, determine the extent and types of recent changes leading to forest degradation, and implement restoration treatments (e.g, Cooper 1960, Covington and Moore 1994a, Covington et al. 1997, Mast et al. 1999, Moore et al. 1999). Environmental activists, such as the member organizations of the Southwest Forest Alliance (SWFA), have also recognized the potential of ecological restoration on National Forest lands. The SWFA developed a document called *Forests Forever!* (SWFA 1996) as a guide to restoration concepts and planning on southwestern forest ecosystems.

The ecological restoration project outlined in this Research Joint Venture report was developed in partnership between the Southwest Forest Alliance and Forest Service (FS) to implement treatments on National Forest lands. The Ecological Restoration Institute of Northern Arizona University (NAU) provided standard sampling methods for monitoring and analysis of the results. We present the initial results of experimental treatments at two sites in Arizona and New Mexico where the SWFA and FS implemented restoration projects based on the *Forests Forever!* model.

In addition to the forest experiments described here, NAU carried out sampling of fire history and forest structure over larger landscapes surrounding the study areas to develop a permanent monitoring system in support of SWFA and FS plans to expand the project beyond the initial experimental areas. At present, expansion has been deferred.

Methods

Study Sites

Discussions among representatives of the Southwest Forest Alliance, the Forest Service, and NAU cooperators were initiated on the Silver City District of the Gila National Forest, NM. On March 17, 1997, representatives of all the cooperators met to discuss layout of a test area at the Mill Sale Area above Pinos Altos. In June, 1997, the **Mill Restoration Demonstration Site** (approximately 6.9 ha) was established. In July, 1997, NAU cooperators met with Kaibab National Forest, AZ, and SWFA staff to

open discussions about a cooperative restoration project on the Williams District, eventually selecting the present **Williams Restoration Demonstration Site**. As with the Gila project, restoration treatments were initiated on a small demonstration area (approximately 16.2 ha).

Study Area – Williams Site, Kaibab National Forest: The Williams site is located on the Williams District, Kaibab National Forest, approximately 17 km east of the city of Williams (Figure 1). The Williams site is representative of managed ponderosa pine forests on the northern Mogollon Plateau. The demonstration site is located within a 400-ha area where restoration activities are being planned.

The Williams site is situated at approximately 2,164 m elevation, and is dominated by ponderosa pine *Pinus ponderosa*, Gambel oak *Quercus gambelii*, and alligator juniper *Juniperus deppeana*. Soils in the Williams site have been mapped as a complex of Lithic Eutroboralfs, clayey-skeletal, montmorillonitic, and Lithic Argiborolls, fine, montmorillonitic. Slopes are nearly level to moderately sloping (0-15%) and soils have formed on basaltic residuum. These are shallow soils with a lithic contact within 50 centimeters of the surface. Deeper Mollic Eutroboralfs, fine, montmorillonitic, can be found in the southern portion of the Wiiliams Site. These soils are also on nearly level to moderately sloping terrain (0-15%), formed on residuum of basalt and cinders. Soils across the larger landscape are a mix of several map units with slopes ranging from 0-40%. Soil families include the units described above across much of the central study area on nearly level to gently sloping terrain. Mollic Eutroboralfs, fine, mixed, and Lithic Eutroboralfs, clayey-skeletal, mixed, are found on Horse Hill where slopes are 15-40%. Typic Argiborolls, clayey-skeletal, montmorillonitic, and Lithic Eutroboralfs occur on moderately steep to steep terrain located at the southeaster portion of the study area. The eastern portion of the study area consists of nearly level to gently sloping terrain (0-15%). Soils are Mollic Eutroboralfs, clayey-skeletal, montmorillonitic, and Typic Argiborolls, fine, montmorillonitic. Ephemeral streams are typically associated with this unit. The site averages 55.3 cm of precipitation annually, with a total annual average snowfall of 179.1 cm. Temperatures range from an average maximum of 28.6°C in July to an average minimum of –7.1°C in January. Weather data are from a permanent station in the city of Williams (elevation 2,134 m) for the period 1897 – 2000.

The land use history of the Williams site is typical of nearby ponderosa pine forests on the Mogollon Plateau of north central Arizona (Fulé et al. 1997). This site experienced an extended period of fire exclusion (1879 to the present), was heavily grazed, railroad logged (Stein 1993), and subsequently managed under a variety of silvicultural prescriptions during the mid to late 1900's (Timber Atlas, Kaibab National Forest, Williams, AZ). Forest inventories of the area conducted in 1901 describe typical forest stands in the immediate area as being dominated by mature ponderosa pines with average diameters of 20 inches (50.8 cm), average total heights of 85 ft (25.9 m), and average stand ages of 190 years (Leiberg 1904).

Study Area – Mill Site, Gila National Forest: The Mill site is located on the Silver City District, Gila National Forest, approximately 17 km northeast of the town of Pinos Altos (Figure 2). The Mill site is approximately 6.9 ha in size and is representative of managed ponderosa pine forests at the southern end of the Mogollon Mountains in New Mexico.

The Mill site is situated at approximately 2,195 m elevation. Tree composition on the site is diverse with a mixture of ponderosa pine, alligator juniper, Gambel oak, silver leaf oak (*Quercus hypoleucoides*), grey oak (*Quercus grisea*), and *Prunus* sp. Species characteristic of mesic environments, southwestern white pine (*Pinus strobiformis*), Douglas-fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*), are present a short distance from the study site. Soils in the study area are a complex of Mollic Eutroboralfs (0-40% slope) and Typic Argiborolls (0-15% slope). Typic Argiborolls are frequently found in open parks and meadows. Parent material throughout the area is basaltic residuum. The site averages 54.9 cm of precipitation annually (Pinos Altos 1911-1970). Annual average snowfall totals are not available for the site. Temperatures range from an average maximum of 30.3°C in July to an average minimum of –6.8°C in January (temperatures recorded from 1914 – 2000 at Mimbres Ranger Station, approximately 20 km east of the study site).

The land use history of the Mill site differs from Williams in the date of initial logging and recent fire history. The Mill site is in close proximity to the Gila Wilderness, which was first placed in "reserve" status in the late 1800's, removing it from consideration as an area for extractive management activities. Logging activity did occur at the Mill site beginning around 1915 and continued throughout the 1900's. Fires have been detected on the site during the mid to late 1900's (T. Heinlein and others, unpublished data). These fires probably influenced the development of the current forest structure, but it is difficult to distinguish effects of fire from those of livestock grazing and harvesting. A survey of forest conditions completed between 1902 and 1904 for the township surrounding the site documented a forest that was approximately 74% ponderosa pine (in terms of total volume) with average tree heights of 113 feet and average diameters of 29 inches (for timber trees). Average stand age was estimated at 218 years (Rixon 1905).

Treatments

By mutual agreement at both the Mill and Williams restoration sites, the SWFA took the lead in restoration prescription development, taking *Forests Forever!* as a starting point. Forest Service cooperators coordinated environmental analysis and implementation of treatment activities. The NAU cooperators participated in the location, design, review, collaboration, development of marking guidelines, development of measurement and monitoring protocols, and in a number of planning meetings and field trips.

Four goals were identified in *Forests Forever!*: (1) restore southwestern forests to fully functioning ecosystems. These systems "evolved with, and depend upon, natural fire, disease, and insect regimes. They can support carefully planned, sustainable levels of resource extraction." (2) Provide jobs for local economies. (3) Plan for future generations. (4) Diversify and stabilize. In pine and oak forests, specific recommendations in *Forests Forever!* were retention of all old-growth (> 120 yr) trees, retention of all pines > 40.6 cm diameter at breast height (dbh, breast height = 1.37 m), and thinning of understory trees to a residual density of 124-618 trees/ha. Where feasible, 17.3 snags/ha > 35.6 cm were to be retained or recruited. Deep duff layers around the boles of large trees were to be cleared if an "extreme fire hazard" existed. No "fragmentation of continuous forest habitat" was permitted and younger forests were to be managed to "provide for the natural variance of habitat conditions" (SWFA 1996:29).

Interpretation of the general goals of *Forests Forever!* into site-specific forest treatments was carried out in stages. Marking for the first stage of tree thinning at the Mill site was done in June, 1997, by T. Schulke (SWFA), H.B. Smith (NAU), and S. Hill and R. Yost (FS, Gila). The first mark was based on evidence of forest structure prior to European settlement (circa 1880), applying methods developed by Covington et al. (1997). On a subsequent visit to the site, SWFA members including T. Schulke and S. Galbreath marked additional trees for retention. At a meeting on May 12, 1998, SWFA members expressed dissatisfaction with the marking approach based on presettlement evidence. Instead, they developed a marking guideline for the Williams site focused on four existing structural elements: (1) open-grown yellow or yellowing pines ["yellow" refers to the characteristic bark color of ponderosa pines > 100-140 yrs old], (2) mid-sized and larger black-jack pines ["black-jack" refers to the darker bark color of younger ponderosa pines], (3) mid-sized and smaller black-jack pines, and (4) small diameter pole stands. The June 9, 1998, version of the Williams site marking guidelines is attached (Exhibit 1).

The Mill site was a true "demonstration" project in that only one treatment was carried out. However, the option existed to design the Williams site for replicated experimentation comparing various treatment alternatives with controls. On May 12, 1998, SWFA representatives M. Hoffman and S. Galbreath chose to do a single *Forests Forever!* treatment, suggesting that the presence of other treatments might confound their intention to demonstrate this approach.

Thinning at the Mill site was initiated in 1998. Harvesting was completed over a two-year period using chainsaws and a farm-tractor yarding system. Fuels were manually raked from around boles of large trees and the site was burned during the summer of 1999 in a lightning-ignited prescribed natural fire. Thinning at the Williams site was carried out in 1999 using chainsaws and a rubber tired shear. Cut material was removed using a rubber-tired skidder. Following harvest, accumulated forest floor material was manually raked from the base of presettlement trees in preparation for future prescribed fires. To

date, a prescription for the initial burning of the Williams site has not been completed. Plans for further treatments and monitoring at both study sites have not been formed.

Monitoring: field measurements

Plot centers were established with tape and compass from surveyed reference points, such as section corners. Plot centers were permanently marked with rebar stakes and slope and aspect were recorded. Twenty plots were established at the Williams site in May 1998 and seven at the Mill site in June 1998. Fewer plots were installed at the Mill site due to logistical and funding constraints. Measurements and plot design were adapted from: (1) the Fire Monitoring system developed by the National Park Service (Reeberg 1995); (2) sampling methods developed for measuring presettlement and contemporary ecosystem structure in southwestern forests (Fulé et al. 1997); and dendroecological sampling techniques (Covington and Moore 1994a).

Overstory trees over breast height (4.5 ft, 137 cm) were measured on a 400m^2 (11.28 m radius) circular fixed-area plot. Species, condition, total height, crown base height, diameter at breast height (dbh), and a preliminary field classification of presettlement or postsettlement origin, were recorded for all live and dead trees over breast height, as well as for stumps and downed trees which surpassed breast height while alive. Tree condition classes were assigned based on a tree, snag and log classification system (Thomas et al. 1979) widely applied in ponderosa pine forests (Covington and Moore 1994a, Fulé et al. 1997). The ten condition classes (1-living, 2-declining, 3-recent snag, 4-loose bark snag, 5-clean snag, 6-snag broken above 1.37m, 7-snag broken below 1.37m, 8-downed, 9-cut stump, 10-burned out stump hole) were used to determine dead tree structure. Potentially presettlement ponderosa pine trees were identified based on size (dsh [diameter at stump height, 40 cm above ground level] > 40 cm) or yellowed bark (White 1985). Trees of all other species were considered as potentially presettlement if dsh > 40 cm, or dsh > 20 cm for oaks, and junipers. All potentially presettlement trees, as well as a random 10% subsample of other trees, were cored with an increment borer at 40 cm above ground level to determine age and past size. Diameter at stump height (dsh) was recorded for all cored trees. All overstory trees were marked with aluminum tags at breast height and tree locations were mapped.

Trees below breast height and shrubs were tallied by condition class and by three height classes (0-40 cm, 40.1-80 cm, and 80.1 – 137 cm) on a nested 100 m^2 (5.64 m radius) subplot. Shrubs over breast height were also measured. Dead woody biomass and forest floor material were measured on a 50 ft planar transect in a random direction from each plot center. Photos were taken to plot center from 11.28 m N and E.

We used the point line-intercept method ("line transects" or "transects") to collect herbaceous and shrub data on all plots. Herbaceous vegetation, for the purposes of this report, includes all vascular plants

that are non-woody in nature. We recorded plant species and substrate every 30 cm along a 50-m line transect oriented upslope with 25 m above and 25 m below the plot center. Species were also recorded within 5 m to either side of each transect, forming a 10 m wide belt on each plot ("belt transect" or "belt"). Heights were recorded for the tallest living plant up to 1.37 m (dbh) encountered at the transect point. In 1997, plants were measured to the nearest 10 cm. Precision was increased in 2000, with measurement to the nearest 1 cm.

At the Mill Site, the timing of data collection varied between years. The pre-treatment data were collected from June 2-4, 1998 and all post-treatment data were collected from May 9-10, 2000. Comparisons between 1998 and 2000 data should be interpreted with consideration for phenological differences between species, maturity at the time of data collection, and presence or absence of annuals, as well as year-to-year variation in precipitation.

Herbaceous data analysis included calculations of plant and substrate frequencies, species richness, and Simpson's Index (richness weighted by frequency). Using the point-line intercept transect methodology, abundance is considered to be equivalent to the frequency of encountering a given species along an herbaceous transect. Note that frequency does not represent a percentage of the whole plant community, because individual plants may be large enough to cross more than one line-transect intercept. The accuracy of frequency measurements on point line-intercept transects is can vary because of the small size of the points. Field technicians also vary in their definitions of rock and wood vs. litter. Thus frequency can be variable between years and between technicians. PC-ORD (MjM Software, Gleneden Beach, OR, 1999) was used for community analyses, including ordinations (non-metric multidimensional scaling, NMDS).

Post Treatment Plot Measurements: Following the prescribed fire treatment on the Mill site, plots were relocated and remeasured. Overstory trees were inspected for changes in condition class and fire effects. Overstory fire effects measurements included crown scorch (average height and percentage) and bole char (minimum and maximum height). Tree regeneration was recorded and herbaceous plant communities re-inventoried using point-intercept and belt transects. Dead woody biomass and forest floor material was also remeasured along the original transects. Burn severity was recorded along the transects for substrate and vegetation. Photos were retaken from their original photo points.

Following tree harvest on the Williams site, plots were relocated and partially remeasured. Since the prescribed fire treatment had not yet been implemented, not all measurements could be taken. Overstory trees were inspected for changes in condition class and fuel transects were remeasured. Following the prescribed fire, the full suite of post treatment plot measurements will be taken.

Laboratory procedures

Plot data was summarized for each site to calculate forest overstory density, basal area, canopy cover, and diameter and age distributions. Tree regeneration and shrub densities were calculated by species and height classes. Herbaceous transect data was used to determine the frequency and abundance of understory plants. Woody debris biomass was calculated using procedures in Brown (1974) and Sackett (1980). Forest floor depth measurements were converted to loading using equations from Ffolliott et al. (1976).

Fire behavior was modeled with the Nexus Fire Behavior and Hazard Assessment System (Scott and Reinhardt 1999). Crown fuels were estimated with allometric equations for foliage and fine twigs of ponderosa pine (Fulé et al. in press), Gambel oak (Clary and Tiedemann 1986), and pinyon and juniper (Grier et al. 1992). Crown volume was estimated by the averages of maximum tree height (top of the canopy) and crown base height (bottom of the canopy). Crown bulk density was calculated as crown biomass divided by crown volume. Identical severe fire weather conditions were used for the simulations at both sites. Fire weather extremes representing the 90^{th} and 97^{th} percentiles of low fuel moisture, high winds, and high temperature were calculated from 30 years of data at Flagstaff, Arizona, using the FireFamily Plus program (Bradshaw and Brittain 1999). Weather values were calculated for the entire fire season (April 23 to October 16) as well as for June, historically the month with the most severe fire weather (Table 2). Fire behavior information from two of the two largest wildfires in northern Arizona, the 1996 Horseshoe (May) and Hochderffer (June) fires, was used to estimate wind gusts during periods of extreme fire behavior. Sustained winds of 51 km/h were commonly observed on these fires.

Passive crownfire behavior (torching) is highly sensitive to crown base height because low crown base values form "ladder" fuels that permit fire to climb into tree canopies. We used stand averages for canopy base height to calculate crown bulk density but used the lowest quintile of canopy base height for calculating susceptibility to passive crownfire.

Results and Discussion

Fire Disturbance History

Williams: A fire history analysis of a 1,200 ha area surrounding the Williams site, conducted independently of this project, is shown in Figure 3. The analysis reveals that frequent fires occurred approximately every 2.8 to 4 years for the analysis period of 1684 to 1879 (Table 1). This fire history and fire exclusion date (1879) is consistent with the results of a nearby fire history study. Fires ceased at the time of Euro-American settlement around 1880 (Fulé et al 1997).

Mill: A fire history analysis of an approximately 260 ha area surrounding the Mill site was conducted independent of this project, but has not yet been completed. However, a preliminary analysis

reveals a more complex fire history than the Williams site. It appears that fires occurred throughout the area beyond 1900 and several fires have occurred in the late 1900's as well.

Fire Behavior Modeling

Canopy fuels and stand structures at both sites are summarized in Table 3. Simulated fires under severe fire weather conditions were surface fires with 2.0 m flame lengths and no canopy consumption (Table 4). The torching indices showed that a wind of about 52-60 km/h would have been needed to cause passive crownfire. If fire were already in the crown or entered from outside the stand, the crowning indices indicated that a windspeed of 67-75 km/h would have sufficed to sustain active canopy burning at either site. Both indices were above the modeled 51 km/h windspeed.

The effect of thinning in changing fire behavior potential at the Williams and Mill sites could not be assessed because crown base heights and tree heights were not measured before treatment. The treated stands had relatively high crown bulk densities, 0.0415-0.0485 kg/m^3 (Table 3). Forest restoration treatments designed to rapidly restore presettlement stand structures on the Coconino and Kaibab National Forests had average canopy bulk densities of 0.0206-0.0337 kg/m^3. Similar thinning treatments that retained more trees ranged from 0.034-0.0587 kg/m^3 and control treatments ranged from 0.0498-0.0835 kg/m^3 (Fulé et al. in press, in review). The minimum quintile crown base heights at Williams and Mill were relatively high (3.64-4.32 m) compared to crown base heights after thinning on the Coconino and Kaibab National Forest sites (2.37-3.84 m) (Fulé et al. in press, in review).

After thinning, the sites were resistant to fires under severe weather conditions, although windspeeds much higher than the simulated 51 km/h were observed during the intense fires of 2000. A wildfire with the simulated flame lengths, 2.0 m, would have a high likelihood of successful suppression using mechanized equipment or indirect attack (Pyne et al. 1996). However, since the post-thinning crown bulk densities were 33-118% higher than crown bulk densities of full restoration sites, resistance to active crownfire was relatively low (crownfire indices of 67-75 km/h compared to 94-127 km/h at full restoration sites). Crownfire resistance could be maintained or enhanced by regular underburning to minimize ladder fuel development and further thinning or snag creation to lower crown bulk density.

Forest Overstory

Williams: Pretreatment overstory tree structure at the Williams site averaged 625.0 trees/ha. Ponderosa pine comprised over 99 percent of the pretreatment live overstory tree structure on the site. Pretreatment basal area averaged 30.70 m^2/ha. Gambel oak and alligator juniper were present but widely scattered across the site. There was an average of 17.50 snags/ha and 53.75 dead down trees/ha on-site prior to treatment.

Post harvest/pre burn overstory tree structure averaged 298.75 live trees/ha (an approximately 52 percent decrease from pretreatment levels). A majority of the thinned trees were small diameter resulting in a modest reduction in basal area to 24.14 m^2/ha. Snags increased by 23 percent to a post harvest level of 22.50 snags/ha. Post harvest dead and down totals were unchanged.

Mill: Pretreatment overstory tree structure at the Mill site averaged 503.6 trees/ha with a mixture of species comprised of ponderosa pine (86 percent), Gambel oak (11 percent), and alligator juniper (3 percent). Pretreatment basal area averaged 37.02 m^2/ha. Snags were abundant with an average of 135.7 snags/ha. Dead down trees averaged 50.0 trees/ha and there were 500 stumps/ha, revealing past silvicultural manipulations on the site.

Post burn overstory tree structure averaged 260.7 trees/ha (a reduction of nearly 50 percent), while basal area was reduced by 34 percent to 24.5 m^2/ha. Species diversity was maintained by the treatment with a post burn composition of ponderosa pine (77 percent), Gambel oak (18 percent), and alligator juniper (5 percent). Fire effects as measured by crown scorch and bole char were minimal. Crown scorch height averaged 0.45 m and bole char height averaged 0.35 m. Snags were only slightly reduced from pretreatment levels and dead down material also increased slightly.

For comparison, full restoration treatments on the Coconino and Kaibab National Forests has post-thinning tree densities of 56.3 trees/ha (Gus Pearson site, Covington et al. 1997) to 140.3 trees/ha (Fort Valley, Fulé et al. in press.). The proportion of thinning in the various treatments at Fort Valley ranged from 77-88% of tree density and 44-65% of basal area. Thus the SWFA treatments were at the low end of the range of forest restoration thinning treatments in the region.

Tree Regeneration

Williams: Pretreatment tree regeneration on the Williams Site averaged 30 seedlings/ha (<137 cm tall). All seedlings observed on the plots were ponderosa pine.

Mill: Pretreatment tree regeneration on the Mill Site averaged 5,228.6 seedlings/ha (<137 cm tall). In contrast to the Williams site, there was a notable diversity of seedling species on the site. Sprouting species such as Gambel oak, gray oak, silver leaf oak and Prunus sp. accounted for 86.3 percent

of the total, while ponderosa pine comprised only 12.6 percent of the seedlings. Over 94 percent of the seedlings were <40 cm tall.

Post burn tree regeneration averaged 2671.44 seedlings/ha, which is a reduction of 49 percent from pretreatment levels. Sprouting species continued to dominate the site (90.4 percent of total). Ponderosa pine seedlings were reduced by 82.6 percent to a post burn average of 114.29 seedlings/ha. *Prunus* sp. and silver leaf oak seedlings were not detected during the post burn measurement. All of the reduction occurred in the <80 cm height classes.

Fuels

Williams: Initial fuel treatments at the Williams site are not complete as of March 2001. However, an examination of the pretreatment and post harvest fuel loadings provides some useful information toward predicting the likely intensity and behavior of a future prescribed burn. Pretreatment fuel loads were light, averaging 36.76 Mg/ha for woody fuel and forest floor fuels combined.

Post harvest/pre burn fuels increased approximately 20 percent to 44.96 Mg/ha. Fuel load additions occurred in all fuel classes except for the 1000 Hour rotten class. It is likely that the decrease in large, rotten fuels is attributable to ground disturbance associated with harvesting activities. An observed increase in litter and duff depths across the site may be partially explained by the redistribution of this rotten material.

Mill: Initial fuel treatments at the Gila site have been completed. Pretreatment fuel loads were light, averaging 47.09 Mg/ha for woody fuel and forest floor fuels combined. Post burn fuels decreased approximately 20.7 percent to 37.34 Mg/ha. The majority of the reduction took place in the forest floor fuel load, which decreased 44.2 percent. Average forest floor fuel depths were lowered from 5.03 cm to 2.35 cm post burn. Post burn woody fuel loadings nearly doubled across the site (10.66 Mg/ha to 20.35 Mg/ha). Net gains were recorded in all woody fuel classes except for 10 Hour fuels (which showed little change), and 1000 Hour rotten fuels, which were reduced by 72.5 percent.

The post burn fuel matrix can be explained by the distribution and moisture of fuels, as well as fire intensity and behavior. Following harvesting activities, fuels were discontinuous and likely had moderate to high moisture contents (particularly the >100 Hour classes). Crown scorch and bole char measurements were also indicative of a low intensity burn. However, it appears that the forest floor and 1000 Hour rotten fuels were sufficiently dry as they were both consumed readily. Burn severity across the site averaged 4.5 on a scale of 1 to 5 (1 = heavily burned and 5 = unburned). Additional fires will be necessary to promote the consumption of 100 and 1000 Hour fuels.

Plant/substrate cover

Williams: Litter and plants were consistently the most frequent ground covers recorded on line-transects in 1998 (Figure 4). Across plots, mean litter and plant frequency were 78% and 10% respectively. As mentioned earlier, no post-treatment data were collected at Williams.

Pre-treatment substrate frequencies were similar for both sites in 1998. Pre-treatment plant ground cover was less than 10% at both sites, which is probably much lower than it was prior to European influences in southwestern forests. Vegetative ground cover is as high as 30-40% in some areas of northern Arizona ponderosa pine forest. No increases in plant cover (with the exception of certain grasses) were detected at the Gila site, perhaps because 2000 was a year of very low precipitation.

Mill: Litter (primarily needles, leaves and cones from tree and shrub species) and plants were the most frequently recorded ground covers along herbaceous transects (Figure 5) in both years (1998 & 2000). However, on some plots, wood and bare soil were more frequent than plants. Averaged across plots, litter, plants, and rock frequencies decreased and wood, soil, bole and scat frequencies increased from 1998 to 2000. Wood was the only substrate that changed significantly from 1998 to 2000 (paired samples t-test, $p=0.048$), most likely due to thinning operations that produced wood that was only partially consumed in the prescribed burn. Duff (partially decomposed organic matter) was combined with litter in all analyses of substrate.

Species richness

Three categories of species richness (number of species) were measured: line transect only, belt transect only and line transect plus belt transect.

Williams: Table 12 summarizes the three categories of species richness at each plot. Between 8 and 28 additional species were recorded on the belts than on transects alone. Some of the common species in that area not recorded on transects were: *Cirsium wheeleri, Festuca arizonica, Hieracium fendleri, Hymenoxys richardsonii, Lupinus kingii, Phlox longifolia, Poa fendleriana, Potentilla subviscosa,* and *Pseudocymopterus montanus.*

Because research sites in ponderosa pine forest can vary greatly based on past and current management history and climatic and geographical differences, comparisons in species richness between sites should be viewed with caution. Pre-treatment species richness at a site on the South Rim of the Grand Canyon in Arizona was comparable to the Gila and Williams sites with a range of species on the belt transects from about 27-35 species per transect. However, species richness on a ponderosa pine sky island on the Arizona Strip north of the Grand Canyon (Mt. Trumbull) was fairly low ranging from about 5-15 species per transect

Mill: Data from both years (1998 & 2000), indicated that between 8 and 31additional species not recorded on transects were found on belt transects (Table 13). Note that unidentified species on the belts may actually have been identified to species on the line transects and thus may explain the species number discrepancies. Some of the most common species in southwestern ponderosa pine forests were not detected by the point-line intercept transects in some of the plots (*Artemisia carruthii, Bahia dissecta, Erigeron divergens, Geranium caespitosum,* and *Poa fendleriana*). None of the three measures of average species richness were significantly different from 1998 to 2000 (paired samples t-test). Species richness was fairly low for this site, perhaps because of the small area. Overall, there was a net loss of species (Table 13).

Simpson's Index

Simpson's index (SI) is a widely used dominance measure of diversity. It emphasizes or gives weight to the most abundant or common species, but is not a direct measure of species richness. SI equals zero when only one individual of each species is recorded. It is reported in this document as 1/SI so that increasing values of SI represent higher diversity.

Williams: In 1998, Simpson's index ranged from 0-11.3 averaging 4.6 across plots (Table 12). Simpson's Index is very difficult to compare between sites because it is even more variable than species richness. SI at the South Rim site averaged approximately 5.7, which is midway between the Gila and Williams sites. SI at the Mt. Trumbull site was the lowest (<4 at most sites).

Mill: Pre-treatment (1998) Simpson's indices ranged from 1.0 to 13.8 (Table 14). Post-treatment Simpson's indices ranged from 0 to 5.4. Average diversity index values dropped by almost half one year following treatment from 6.5 in 1998 to 3.5 in 2000 although this difference is not significant (paired samples t-test, $p=0.012$).

Family frequency

Williams: The most frequently recorded family in all 20 plots was the Poaceae (grasses). Other common families (Table 15) were the Cyperaceae (sedges), Asteraceae (asters), and Fabaceae (legumes). Again, it is probable that the early sampling and small sample size have skewed the results. Certain families and species may not be represented because they bloom or germinate (monsoonal annuals) later in the year and are more obvious at that time, such as Caryopyllaceae, Geraniaceae, Polemoniaceae, and Rubiaceae. As a means for comparison, 30 families were recorded on a larger landscape scale on several EM plots (vs. 8 on the EB plots) that cover a larger area of the Williams site.

Mill: We observed a total of eight families on the demonstration plots. The most frequent families recorded pre- and post-treatment were Asteraceae (asters), Poaceae (grasses), and Fabaceae

(legumes). Post-treatment (2000) frequency of the Poaceae family (all perennials) increased in all plots on the site. We observed a similar pattern at the Ecological Restoration Institute's Grand Canyon EM and EB plots suggesting that members of the Poaceae may be more drought-resistant and more tolerant of disturbance than most other families. All other families decreased overall following treatment. However, the Asteraceae, as a percentage of the plant community, increased (Table 16). Very few families are represented in comparison to other study areas (Springer et al. 2000). Many families may be under-represented (such as Scrophulariaceae) or absent in EB plots most likely due to a limited area of coverage in combination with an early sampling time (May & June). As a means for comparison, 25 families were recorded on the 17 Ecosystem Monitoring (EM) plots that cover a larger area of the Gila Mills site.

Cover or Frequency

Individual species cover (frequency) highlights the dominant species and documents changes in those species from year to year. Both absolute and relative species frequencies are reported.

Williams: The most frequent species were all grasses (Poaceae). Common perennial grasses recorded along the herbaceous transects include (Table 17): *Blepharoneuron tricholepis, Elymus elymoides* ssp. *elymoides, Poa fendleriana, Muhlenbergia montana, Festuca arizonica,* and *Bouteloua gracilis*. Other frequent species include: *Lupinus kingii, Artemisia carruthii, Cirsium wheeleri, Phlox longifolia, Potentilla crinata, and Hymenoxys richardsonii.*

Mill: Most species showed minor changes in frequency following treatment (Table 18). However, average frequencies of *Bromus ciliatus* ($p=0.01$) increased and *Carex geophila* ($p=0.03$) decreased significantly between sampling years (paired samples t-test). According to the USFS Fire Effects Information System (FEIS) database, (www.fs.fed.us/database/feis), *B. ciliatus* reproduces exclusively by seed and is generally not very tolerant of moderate and high intensity fire. Its populations did not experience negative effects from the prescribed burn at this site. *C. geophila* appears to be shade-tolerant and is often indicative of a late seral stage in ponderosa pine forest (J. Springer, personal observation). The New Mexico Rare Plants List (nmrareplants.unm.edu) lists *C. geophila* as fairly widespread but not abundant in New Mexico.

Exotic species

At both Gila and Williams, the presence of several species of non-native plants was recorded on the belt transects although no non-native species were observed on the line transects (Table 19 and 20).

Williams: As mentioned earlier, no species were recorded on the line transects, so no cover data is available. However presence of exotic species was recorded on 1-13 of the belts depending on the

species (Table 19). Of particular concern is the presence of *Bromus tectorum* (cheatgrass), which colonizes rapidly following burning. *Verbascum thapsus* also colonizes wide areas following disturbance and its seeds remain viable in the soil seed bank for long periods of time. However, it is generally not considered to be a noxious species.

Mill: Of 7 belt transects, the number of occurrences for each species was relatively low (1-6). *Vicia villosa* (winter vetch) occurred the most (6 belts) between the two years (1998 & 2000). Winter vetch is a common forage species and is widespread throughout the U.S. *Verbascum thapsus* and *Poa pratensis* are of most concern because of the ability of mullein to colonize large areas following disturbance and the invasiveness of Kentucky bluegrass.

Rare species

No federally listed threatened or endangered species were recorded at either site. Species are considered rare, despite their listed status, if they are locally not very abundant or have a limited range.

Williams: *Sporobolus interruptus* was recorded in the demonstration unit. It is listed as a FS sensitive species. Several other FS sensitive species were recorded throughout the larger, landscape study area.

Mill: *Senecio neomexicanus* var. *metcalfei* was recorded at the Gila Mills site. This species is listed as a sensitive species by the BLM because of its small range. *Carex geophila* and *Conopholis alpina* were both recorded and are both listed on the NM Rare Plants list for consideration as rare species. However, neither species is currently listed.

Shrubs

Shrub abundance and diversity is low in many southwestern ponderosa pine forests. Historical abundance is largely unknown. Because shrubs make up a large portion of the diet of both deer and elk, they presumably have decreased in number since the removal of large predators and cessation and suppression of fires that stimulate reproduction in certain species.

Williams: Shrubs were very infrequent at Williams. No shrubs were recorded on the line transects. *Ceanothus fendleri* (buckbrush) was recorded on two belt transects and *Ericameria nauseosa* ssp. *nauseosa* (rabbitbrush) was recorded on 8 plots (40%).

Mill: Three species were recorded: *Quercus hypoleucoides* (silverleaf oak), *Quercus grisea* (gray oak) and *Ceanothus fendleri* (buckbrush). Silverleaf oak was recorded on the belt transects of five plots pre- and post-treatment. However, its cover decreased on the line transects, but this decrease was probably due to a loss of branches in the burn that formerly intercepted the transect. Gray oak did not intercept the line transects pre- or post-treatment. Its presence on the belt transects decreased from 71%

to 29% of the plots following restoration treatments. Many oak species sprout vigorously following fire, so this decrease is probably temporary. Buckbrush cover increased from less than 1% to 2.5% on one plot following the burn.

Community analysis

An NMDS ordination (nonmetric multidimensional scaling) on the Mill site (Figure 6) indicates that the plant community prior to treatment was fairly uniform but plots were less similar following restoration treatments. All factors exhibit high variability between plots, confounding the changes from year to year. These differences cannot be solely attributed to treatment effects because of the absence of control plots and environmental data. Year to year variation in climate and precipitation, herbivory, phenological differences, and other non-treatment factors also contribute to differences between plots. Herbaceous plant response to ecological restoration treatments (thinning and burning) in southwestern ponderosa pine forests is highly dependant on weather conditions and numerous site factors, including fuel loading, fire history, past management practices, and the propagules available on site or nearby for colonization. Because the interval between burning and data collection at the Gila Mill Site was only 9 months, and precipitation was very low during that time, the data should be considered to be preliminary. Neither site had a control area with which to compare data. The Williams site was thinned but not burned, and herbaceous data have not yet been collected post-treatment at that site. Year to year variation is high due to climatic factors, especially higher temperatures and lower levels of precipitation, and natural variability between plots. The Ecosystem Monitoring (EM) plots at both the Gila and Williams site are used in this report as a "control" of sorts. These plots were established over a larger area than the Experimental Block (EB) plots and provide a set of average conditions for this general area. They were measured a month apart in the same year as the EB plots. The EM plots also represent a larger sample size than is reported for EB plots in this report

Comprehensive species list

All species recorded on herbaceous and belt transects, including trees and shrubs, are listed for the Williams site (Appendix A) and Gila site (Appendix B).

Archival donations list

All plant collections at the Williams site are listed in Appendix C and in Appendix D for the Gila site. The herbarium where the specimen was donated is listed for future reference.

Conclusions

This project provided an important opportunity for the Southwest Forest Alliance to demonstrate and develop a distinct approach to forest restoration. The Forest Service, on two National Forests and the Rocky Mountain Research Station, and the Ecological Restoration Institute of Northern Arizona University cooperated with SWFA to implement and monitor the test sites on the Gila (NM) and Kaibab (AZ) National Forests. Permanent monitoring plots were established in 1998, before treatment, and remeasured in 2000, after thinning and burning on the Gila site and thinning on the Kaibab site. In terms of immediate treatment effects, the thinnings were relatively moderate with less reduction in tree density (50-52% decline) and basal area (21-34% decline) than that achieved in other restoration treatments in the region. Post-treatment wildfire behavior under severe weather conditions was predicted to be a controllable surface fire, although crown bulk densities were relatively high, meaning that crownfire remained a possibility with higher winds (67-75 km/h). Tree torching (passive crownfire) was predicted to occur with windspeeds of 52-60 km/h, an improvement over untreated stands and within the range of nearby thinning treatments. Understory effects were light, with few exotic species encountered in 2000. Plant community effects cannot be adequately assessed immediately after treatment, especially because of the drought conditions in the Southwest during 2000. Only the Gila site was burned; the prescribed natural fire was not severe and tree scorch and char were minimal.

Additional information is needed to fully evaluate the restoration treatments. Treatment costs should be assessed in light of the degree and longevity of crownfire resistance, compared with alternative treatments. Further treatment prescriptions have not yet been developed for burning and repeated entries (if any) for additional thinning. The benefits of relatively dense stands of retained trees should be compared with competitive influences on the development and survival of large, mature trees and diverse and productive understory plant communities. The light touch of thinning and burning at the SWFA should be contrasted with more extensive soil and heat damage at other treatment sites in the region.

The SWFA demonstration sites represent a valuable addition to the range of restoration treatment alternatives in the Southwest. Completion of initial treatments (prescribed burning of the Kaibab site) and development of long-term management strategies would be a useful next step.

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Table 1. Fire return intervals at the Williams Study site. Statistical analysis was carried out in three categories: (1) all fire years, including those represented by a single fire scar; (2) fire years in which 10% or more of the recording samples were scarred; and (3) fire years I which 25% or more of the recording sample trees were scarred. n = 35 samples.

Site/Analysis Period	Number of Intervals	Mean (MFI)	Median	Standard Deviation	Min	Max	WMPI (Weibull median probability interval)
Williams / 1684 – 1879							
All scars	84	2.76	2.00	1.52	1	8	2.60
10% scarred	72	3.22	3.00	1.62	1	8	3.08
25% scarred	58	4.00	4.00	1.94	1	8	3.85

Table 2. Fuel moisture, wind, and temperature for Flagstaff, Arizona, 1970-1999. The 90th and 97th percentiles are shown for the entire fire season (April 23 to October 16) and for the month of June.

Variable	Fire Season 90th percentile	Fire Season 97th percentile	June 90th percentile	June 97th percentile
1 H moisture (%)	3.2	3.0	2.3	2.2
10 H moisture (%)	4.4	4.0	3.0	3.0
100 H moisture (%)	7.2	6.5	5.0	4.7
Wind speed (km/h)	30.1	38.1	34.0	42.5
Temperature (°C)	28	28	32	32

Table 3. Forest stand structure and crown fuels at the Williams (Kaibab National Forest) and Mill (Gila National Forest) study sites.

	Williams	Mill
Crown bulk density (kg/m^3)	0.0485	0.0415
Average crown base height (m)	4.79	8.72
Low quintile crown base ht. (m)	3.64	4.32
Crown fuel load (Mg/ha)	7.14	7.91
Stand height (m)	19.5	27.8
Pine density (trees/ha)	297.5	200.0
Oak/locust density (trees/ha)	1.3	50.0
Pinyon/juniper density (trees/ha)	0	14.3

Table 4. Fire behavior outputs using the June 97th percentile weather conditions with 51 km/h winds and lowest quintile crown base height. Foliar moisture content was held constant at 100% and wind reduction factor was 0.3. Average slope was 5.2% at Williams and 10% at Mill.

	Williams	Mill
Fire type[A]	Surface	Surface
Crown percent burned	0%	0%
Rate of spread (m/min)	12.4	12.5
Heat/area (kJ/m^2)	5	5
Flame length (m)	2.0	2.0
Crown Fire Outputs		
Torching index (km/h)	52.1	60.5
Crowning index (km/h)	67.2	75.0

[A] Fire types are (1) surface, (2) passive crownfire or "torching," (3) active crownfire

Table 5. Comparison of pre treatment and post harvest tree densities and basal area at Williams site.

Williams Site Kaibab NF Trees/ha	Species	Pre Treatment Mean	Pre Treatment (S.E.)	Post Harvest Mean	Post Harvest (S.E.)
Live Trees	PIPO	623.75	(99.89)	297.50	(44.13)
	QUGA	1.25	(1.25)	1.25	(1.25)
	Total :	625.00	(99.72)	298.75	(43.99)
Snags	PIPO	16.25	(5.52)	21.25	(5.22)
	QUGA	1.25	(1.25)	1.25	(1.25)
	Total :	17.50	(5.47)	22.50	(5.41)
Dead Down	PIPO	53.75	(9.81)	53.75	(9.81)
	QUGA	0.00	(0.00)	0.00	(0.00)
	Total	53.75	(9.81)	53.75	(9.81)
Cut Stumps	PIPO	148.75	(33.91)	470.00	(93.83)
	QUGA	0.00	(0.00)	0.00	(0.00)
	Total	148.75	(33.91)	470.00	(93.83)

Williams Site Kaibab NF BA m^2/ha	Species	Pre Treatment Mean	Pre Treatment (S.E.)	Post Harvest Mean	Post Harvest (S.E.)
Live Trees	PIPO	30.68	(2.61)	24.12	(2.15)
	QUGA	0.02	(0.02)	0.02	(0.02)
	Total :	30.70	(2.61)	24.14	(2.15)

Table 6. Comparison of pre treatment and post harvest tree densities and basal area at Mill site.

Mill Site Gila NF Trees/ha	Species	Pre Treatment Mean	(S.E.)	Post Burn Mean	(S.E.)
Live Trees	JUDE	17.86	(7.14)	14.29	(7.43)
	PIPO	432.14	(51.38)	200.00	(43.30)
	QUGA	53.57	(26.41)	46.43	(27.51)
	Total :	503.57	(48.71)	260.72	(51.43)
Snags	JUDE	17.86	(8.99)	10.71	(7.43)
	PIPO	107.14	(27.66)	110.71	(27.20)
	QUGA	10.71	(7.43)	10.71	(7.43)
	Total :	135.71	(31.68)	132.13	(29.31)
Dead Down	JUDE	3.57	(3.57)	3.57	(3.57)
	PIPO	42.86	(19.45)	46.43	(21.43)
	QUGA	3.57	(3.57)	3.57	(3.57)
	Total :	50.00	(17.62)	53.57	(19.45)
Cut Stumps	JUDE	0.00	(0.00)	10.71	(7.43)
	PIPO	496.43	(136.11)	721.43	(184.23)
	QUGA	3.57	(3.57)	10.71	(7.43)
	Total:	500.00	(136.39)	742.86	(182.88)

Mill Site Gila NF BA m^2/ha	Species	Pre Treatment Mean	(S.E.)	Post Burn Mean	(S.E.)
Live Trees	JUDE	0.15	(0.11)	0.13	(0.11)
	PIPO	32.47	(6.77)	20.34	(5.53)
	QUGA	4.40	(2.06)	4.02	(2.07)
	Total :	37.02	(6.27)	24.50	(4.83)

Table 7. Pre treatment tree regeneration at Williams site.

Williams Site Kaibab NF Regeneration	Species	Pre Treatment 0-40 cm Mean	(S.E.)	40-80 cm Mean	(S.E.)	80-137cm Mean	(S.E.)
Live	PIPO	5.00	(5.00)	10.00	(6.89)	15.00	(8.19)
	Total :	5.00	(5.00)	10.00	(6.89)	15.00	(8.19)

Table 8. Pre treatment tree regeneration at Mill site.

Mill Site Gila NF Regeneration	Species	Pre Treatment 0-40 cm Mean	(S.E.)	40-80 cm Mean	(S.E.)	80-137cm Mean	(S.E.)
Live	JUDE	14.29	(14.29)	28.57	(28.57)	14.29	(14.29)
	PIPO	628.57	(443.85)	28.57	(18.44)	0.00	(0.00)
	PRUN SP	14.29	(14.29)	0.00	(0.00)	0.00	(0.00)
	QUGA	3728.57	(657.45)	114.29	(98.63)	0.00	(0.00)
	QUGR	542.86	(363.75)	100.00	(100.00)	0.00	(0.00)
	QUHY	0.00	(0.00)	0.00	(0.00)	14.29	(14.29)
	Total :	4928.58	(842.25)	271.43	(150.74)	28.58	(18.44)

Table 9. Post burn tree regeneration at Mill site.

Mill Site Gila NF Regeneration	Species	Post Burn 0-40 cm Mean	(S.E.)	40-80 cm Mean	(S.E.)	80-137 cm Mean	(S.E.)
Live	JUDE	85.71	(55.33)	42.86	(42.86)	14.29	(14.29)
	PIPO	100.00	(57.74)	0.00	(0.00)	14.29	(14.29)
	PRUN SP	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
	QUGA	1785.71	(447.97)	371.43	(191.13)	0.00	(0.00)
	QUGR	242.86	(160.14)	14.29	(14.29)	0.00	(0.00)
	QUHY	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
	Total :	2214.28	(575.46)	428.58	(155.40)	28.58	(18.44)

Table 10. Comparison of pre treatment and post harvest fuel loadings at Williams site.

Williams Site-Kaibab NF	**Pre Treatment**		**Post Harvest**	
Woody Fuel Loadings, Mg/ha	Mean	(S.E.)	Mean	(S.E.)
0 – 0.635 cm diameter	0.21	0.05	0.47	0.10
0.635 – 2.54 cm diameter	1.27	0.32	2.75	0.75
2.54 – 7.62 cm diameter	4.57	2.86	4.29	1.74
> 7.62 cm diameter sound	5.56	2.26	10.12	3.76
> 7.62 cm diameter rotten	2.19	1.54	0.33	0.25
Sub Total	13.81	3.97	17.96	4.73
Litter Loading, Mg/ha	4.64	2.86	6.77	1.16
Duff Loading, Mg/ha	18.31	2.22	20.23	2.84
Total Loadings: Mg/ha	36.76	4.11	44.96	4.64

Duff and Litter Depths, cm	**Mean**	**(S.E.)**	**Mean**	**(S.E.)**
Litter, cm	0.64	0.10	0.93	0.16
Duff, cm	2.53	0.31	2.79	0.39

Table 11. Comparison of pre treatment and post burn fuel loadings at Mill site.

Mill Site-Gila NF	**Pre Treatment**		**Post Burn**	
Woody Fuel Loadings, Mg/ha	Mean	(S.E.)	Mean	(S.E.)
0 – 0.635 cm diameter	0.15	0.06	0.37	0.07
0.635 – 2.54 cm diameter	2.56	0.81	2.01	0.83
2.54 – 7.62 cm diameter	1.23	0.85	6.56	5.20
> 7.62 cm diameter sound	0.69	0.69	9.74	4.29
> 7.62 cm diameter rotten	6.04	3.95	1.66	1.42
Sub Total	10.66	4.26	20.35	6.18
Litter Loading, Mg/ha	16.15	3.27	5.21	0.81
Duff Loading, Mg/ha	20.28	4.59	11.79	2.52
Total Loadings: Mg/ha	47.09	7.67	37.34	7.20

Duff and Litter Depths, cm	**Mean**	**(S.E.)**	**Mean**	**(S.E.)**
Litter, cm	2.23	0.45	0.72	0.11
Duff, cm	2.80	0.63	1.63	0.35

Table 12. Species richness and Simpson's diversity index at each plot at the Williams site.

	Species richness			Simpson's Index
Plot #	**Transect**	**Belt**	**Belt+Transect**	
1	5	32	33	7.5
2	9	30	30	4.5
3	3	26	28	3.3
4	5	22	23	7.2
5	5	18	22	7
6	3	26	26	2.3
7	4	22	24	5
8	1	16	16	0
9	8	33	33	4.4
10	7	23	25	11.3
11	4	17	19	10
12	4	17	21	2.1
13	2	22	22	0
14	2	8	10	1.8
15	5	28	28	3
16	6	26	32	6
17	4	25	26	10
18	3	11	13	2.5
19	7	29	34	2.7
20	1	18	19	1
Mean	**4.4**	**22.5**	**24.2**	**4.6**

Table 13. Species richness at each plot pre-treatment (1998) and 1-year post-treatment (2000) at the Mill site.

	Transect			Belt			Transect+Belt		
Plot #	**1998**	**2000**	**Diff.**	**1998**	**2000**	**Diff.**	**1998**	**2000**	**Diff.**
1	8	7	1	27	27	0	30	27	-3
2	6	4	-2	13	24	11	14	24	10
3	6	8	2	37	32	-5	37	33	-4
4	5	2	-3	30	21	-9	31	21	-10
5	1	2	1	27	18	-9	27	18	-9
6	9	4	-5	30	26	-4	32	26	-6
7	5	3	-2	31	26	-5	33	27	-5
Mean	**5.7**	**4.3**	**-1.4**	**27.9**	**24.9**	**-3**	**29.1**	**25.1**	**-4**

Table 14. Simpson's diversity index (SI) pre-treatment (1998) and 1-year post-treatment (2000) at each plot at the Mill site.

Plot #	1998	2000
1	13.8	5.4
2	3.2	4.5
3	7	7
4	4.4	0
5	1	1.7
6	8.9	0
7	7	6
Mean	**6.5**	**3.5**

Table 15. Average family frequencies across all 20 plots at the Williams site.

Family	Absolute (%)	Relative (%)
Asteraceae	0.9	11.0
Cyperaceae	0.6	12.2
Fabaceae	1.2	1.1
Poaceae	1.9	70.5
Polemoniaceae	0.6	2.9
Rosaceae	0.6	1.3
Scrophulariaceae	0.6	1.0

Table 16. Family frequencies across all plots at the Mill site (n=7).

	Absolute Freq. (%)		Relative Freq. (%)	
	1998	2000	1998	2000
Apiaceae	0.6	0	2.4	0
Asteraceae	7.8	6	27.6	30.5
Boraginaceae	1.2	0.6	4.4	1.8
Cyperaceae	3.6	3	26.6	19.3
Fabaceae	5.4	1.8	20.7	9.2
Geraniaceae	0.6	0	1.6	0
Malvaceae	0.6	0	1.6	0
Poaceae	4.2	6.6	15.2	39.2

Table 17. Species frequency at each plot at the Williams site.

Plot #	Species Name	Absolute (%)	Relative (%)
1	*Blepharoneuron tricholepis*	1.2	20.0
	Carex sp.	1.2	20.0
	Elymus elymoides ssp. elymoides	1.2	20.0
	Hymenoxys bigelovii	0.60	10.0
	Poa fendleriana	1.8	30.0
2	*Agoseris sp.*	0.60	3.6
	Artemisia carruthii	0.60	3.6
	Blepharoneuron tricholepis	6.6	39.3
	Bouteloua gracilis	0.60	3.6
	Cirsium wheeleri	1.2	7.1
	Elymus elymoides ssp. elymoides	4.8	28.6
	Lupinus kingii	1.2	7.1
	Poa fendleriana	0.60	3.6
	Vicia sp.	0.60	3.6
3	*Blepharoneuron tricholepis*	0.60	20.0
	Carex sp.	0.60	20.0
	Poa fendleriana	1.8	60.0
4	*Artemisia carruthii*	0.60	11.1
	Bouteloua gracilis	1.8	33.3
	Elymus elymoides ssp. elymoides	1.2	22.2
	Muhlenbergia montana	0.60	11.1
	Poa fendleriana	1.2	22.2
5	*Blepharoneuron tricholepis*	0.60	14.3
	Cirsium wheeleri	0.60	14.3
	Elymus elymoides ssp. elymoides	1.8	42.9
	Hymenoxys richardsonii	0.60	14.3
	Penstemon virgatus	0.60	14.3
6	*Blepharoneuron tricholepis*	1.2	22.2
	Phlox longifolia	0.60	11.1
	Poa fendleriana	3.6	66.7
7	*Carex sp.*	0.60	16.7
	Cirsium wheeleri	0.60	16.7
	Elymus elymoides ssp. elymoides	1.8	50.0
	Festuca arizonica	0.60	16.7
8	*Carex sp.*	0.60	100.0
9	*Blepharoneuron tricholepis*	4.2	28.0
	Bouteloua gracilis	0.60	4.0
	Elymus elymoides ssp. elymoides	0.60	4.0
	Festuca arizonica	0.60	4.0
	Lycurus phleoides	0.60	4.0
	Muhlenbergia montana	6.0	40.0
	Poa sp.	1.2	8.0
	Potentilla crinita	1.2	8.0
10	*Blepharoneuron tricholepis*	1.8	30.0
	Bouteloua gracilis	0.60	10.0
	Carex sp.	0.60	10.0
	Elymus elymoides ssp. elymoides	0.60	10.0

	Hymenoxys richardsonii	1.2	20.0
	Muhlenbergia montana	0.60	10.0
	Potentilla subviscosa	0.60	10.0
11	*Blepharoneuron tricholepis*	0.60	20.0
	Hymenoxys richardsonii	0.60	20.0
	Muhlenbergia montana	1.2	40.0
	Solidago sp.	0.60	20.0
12	*Blepharoneuron tricholepis*	2.4	22.2
	Bouteloua gracilis	0.60	5.6
	Elymus elymoides ssp. elymoides	0.60	5.6
	Muhlenbergia montana	7.2	66.7
13	*Bouteloua gracilis*	0.60	50.0
	Elymus elymoides ssp. elymoides	0.60	50.0
14	*Festuca arizonica*	6.0	71.4
	Muhlenbergia montana	2.4	28.6
15	*Blepharoneuron tricholepis*	0.60	3.4
	Bouteloua gracilis	1.8	10.3
	Carex sp.	0.60	3.4
	Festuca arizonica	7.8	44.8
	Muhlenbergia montana	6.6	37.9
16	*Blepharoneuron tricholepis*	0.60	7.7
	Bouteloua gracilis	3.0	38.5
	Carex sp.	0.60	7.7
	Cirsium wheeleri	1.2	15.4
	Elymus elymoides ssp. elymoides	1.2	15.4
	Festuca arizonica	1.2	15.4
17	*Elymus elymoides ssp. elymoides*	0.60	20.0
	Muhlenbergia montana	1.2	40.0
	Phlox sp.	0.60	20.0
	Poa fendleriana	0.60	20.0
18	*Bouteloua gracilis*	0.60	12.5
	Elymus elymoides ssp. elymoides	1.2	25.0
	Muhlenbergia montana	3.0	62.5
19	*Carex sp.*	0.60	3.7
	Elymus elymoides ssp. elymoides	1.2	7.4
	Festuca arizonica	9.6	59.3
	Muhlenbergia montana	1.2	7.4
	Poa sp.	0.60	3.7
	Poa fendleriana	2.4	14.8
	Schizachyrium scoparium	0.60	3.7
20	*Bouteloua gracilis*	1.8	100.0

Table 18. Species frequencies at each plot pre-treatment (1998) and 1-year post-treatment (2000) at the Mill site.

		Absolute Freq. (%)		Relative Freq. (%)	
	Species Name	**1998**	**2000**	**1998**	**2000**
Plot 1	*Achillea millefolium var. occidentalis*	1.8	1.2	27.3	14.3
	Artemisia carruthii	0	1.2	0	14.3
	Artemisia dracunculus	0.6	0	9.1	0
	Artemisia ludoviciana	0.6	0	9.1	0
	Bromus ciliatus	0.6	3.6	9.1	42.9
	Carex geophila	0.6	0	9.1	0
	Carex sp.	0	0.6	0	7.1
	Elymus elymoides ssp. elymoides	0.6	0	9.1	0
	Koeleria macrantha	0	0.6	0	7.1
	Lupinus neomexicanus	0.6	0.6	9.1	7.1
	Senecio neomexicanus var. metcalfei	1.2	0	18.2	0
	Senecio wootonii	0	0.6	0	7.1
Plot 2	*Achillea millefolium var. occidentalis*	6	2.4	55.6	40.0
	Antennaria umbrinella	0.6	0	5.6	0
	Bromus ciliatus	0	1.2	0	20.0
	Carex geophila	1.2	0	11.1	0
	Carex sp.	0	1.8	0	30.0
	Elymus elymoides ssp. elymoides	0.6	0.6	5.6	10.0
	Lupinus neomexicanus	1.2	0	11.1	0
	Pseudocymopterus montanus	1.2	0	11.1	0
Plot 3	*Achillea millefolium var. occidentalis*	0	3.6	0	27.3
	Artemisia carruthii	0	1.2	0	9.1
	Bromus ciliatus	0.6	2.4	6.7	18.2
	Carex occidentalis	1.8	0	20.0	0
	Carex sp.	0	1.2	0	9.1
	Elymus elymoides ssp. elymoides	2.4	3	26.7	22.7
	Koeleria macrantha	0	0.6	0	4.5
	Lithospermum multiflorum	0	0.6	0	4.5
	Lupinus neomexicanus	1.8	0	20.0	0
	Senecio eremophilus	0.6	0	6.7	0
	Senecio sp.	0	0.6	0	4.5
	Vicia ludoviciana	1.8	0	20.0	0
Plot 4	*Achillea millefolium var. occidentalis*	2.4	0.6	26.7	50.0
	Carex sp.	1.8	0	20.0	0
	Elymus elymoides ssp. elymoides	3.6	0	40.0	0
	Lupinus neomexicanus	0.6	0	6.7	0
	Poa fendleriana	0	0.6	0	50.0
	Thermopsis divaricarpa	0.6	0	6.7	0
Plot 5	*Bromus ciliatus*	0	0.6	0	20.0

	Carex occidentalis	1.2	0	100.0	0
	Carex sp.	0	2.4	0	80.0
Plot 6	*Achillea millefolium var. occidentalis*	3.6	0	27.3	0
	Artemisia carruthii	0	0.6	0	25.0
	Artemisia sp.	1.8	0	13.6	0
	Elymus elymoides ssp. elymoides	1.2	0.6	9.1	25.0
	Geranium sp.	0.6	0	4.5	0
	Lithospermum sp.	1.8	0	13.6	0
	Lupinus neomexicanus	1.8	0.6	13.6	25.0
	Senecio neomexicanus var. metcalfei	1.2	0	9.1	0
	Sphaeralcea sp.	0.6	0	4.5	0
	Vicia ludoviciana	0	0.6	0	25.0
	Vicia sp.	0.6	0	4.5	0
Plot 7	*Carex sp.*	1.8	0.6	42.9	25.0
	Elymus elymoides ssp. elymoides	0	0.6	0	25.0
	Grindelia aphanactis	0.6	0	14.3	0
	Lithospermum sp.	0.6	0	14.3	0
	Lupinus neomexicanus	0.6	0	14.3	0
	Senecio actinella	0.6	1.2	14.3	50.0

Table 19. Exotic species occurrence on belt transects pre-treatment (1998) and 1-year post-treatment (2000) at the Williams site.

Species	# occurrences
Bromus tectorum	8
Dactylis glomerata	2
Taraxacum officinale	10
Tragopogon dubius	3
Verbascum thapsus	13

Table 20. Exotic species occurrence on belt transects pre-treatment (1998) and 1-year post-treatment (2000) at the Mill site. No non-native species were recorded on the line transects.

Species	1998	2000
Dactylis glomerata	2	1
Poa pratensis	1	1
Taraxacum officinale	1	0
Verbascum thapsus	0	1
Vicia villosa	2	4

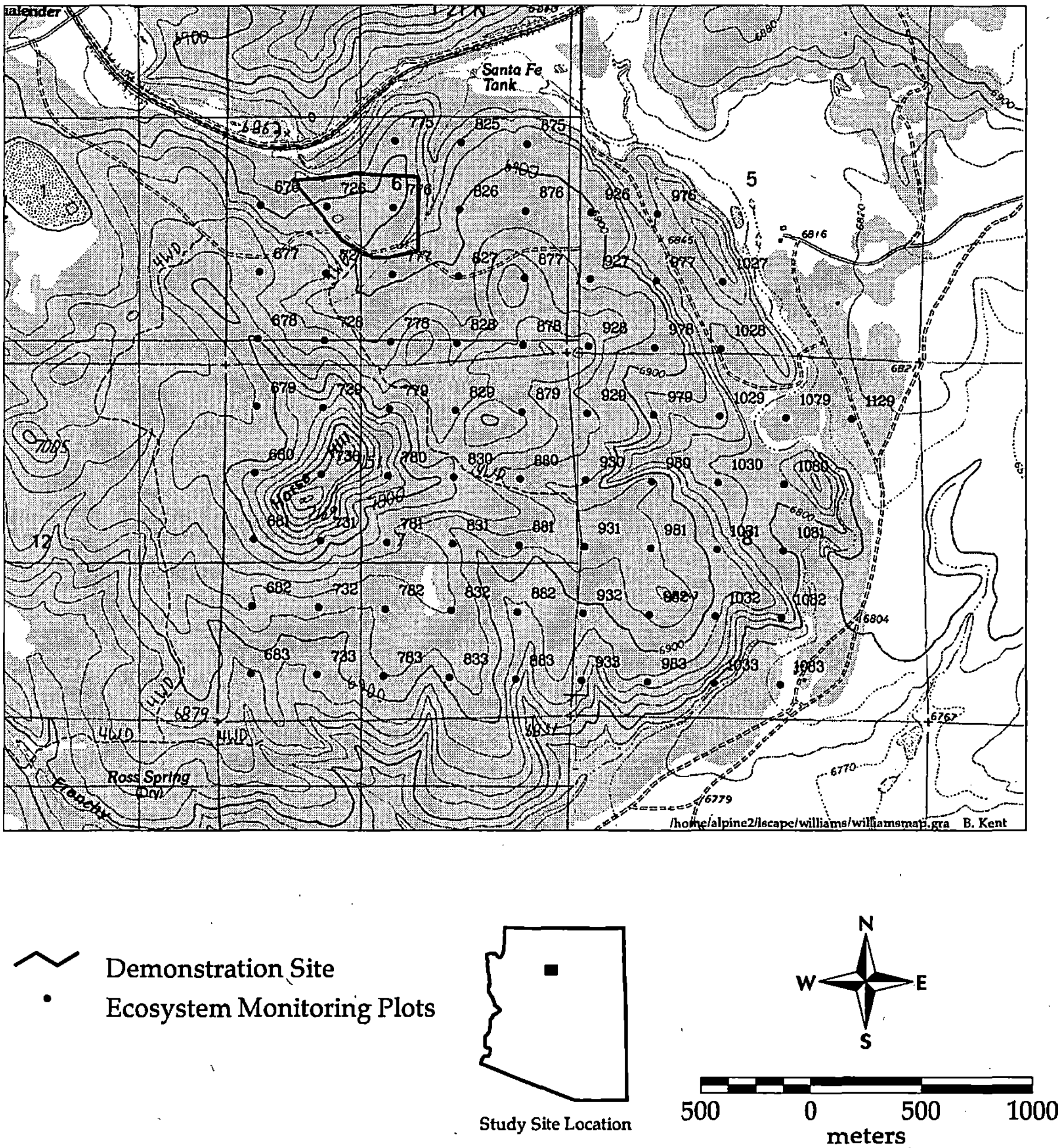
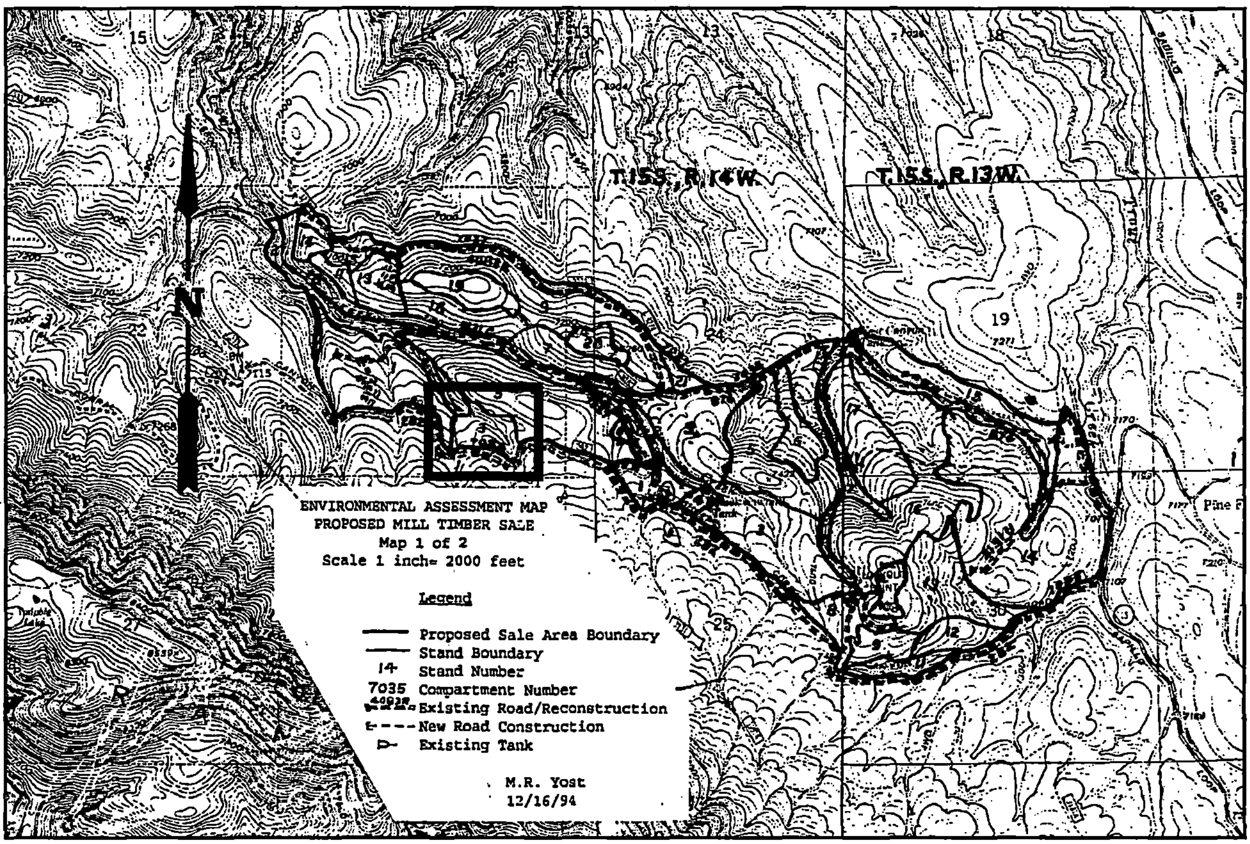


Figure 1. Williams study area on the Kaibab National Forest, AZ. The initial demonstration treatment site is outlined. The monitoring plot grid covers a larger area, including the future treatment sites and adjacent control (boundaries have not yet been determined).



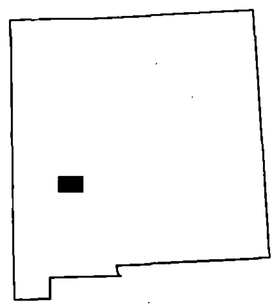
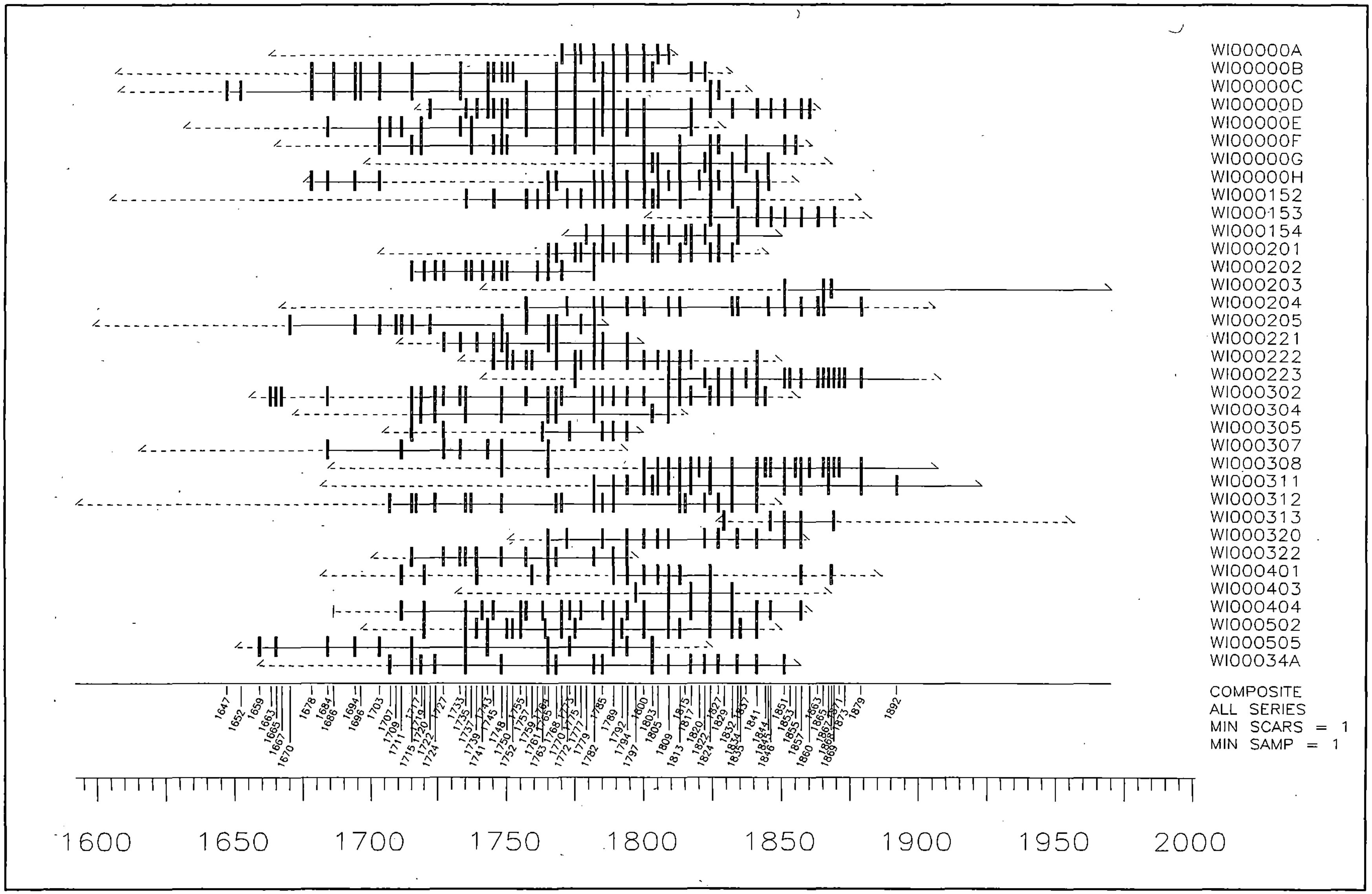


Figure 2. Mill study area on the Gila National Forest, NM. The initial treatment area is indicated in the box at left center.

Figure 3. Fire history of Williams site.



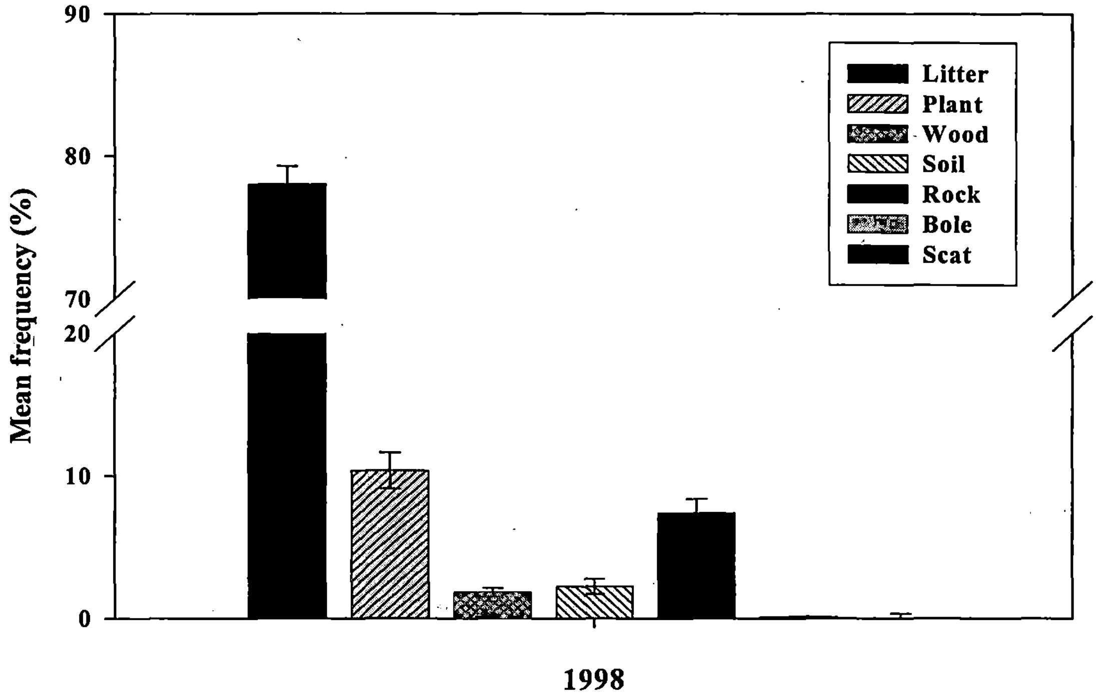


Figure 4. Pre-treatment (1998) substrate frequencies at the Williams site.

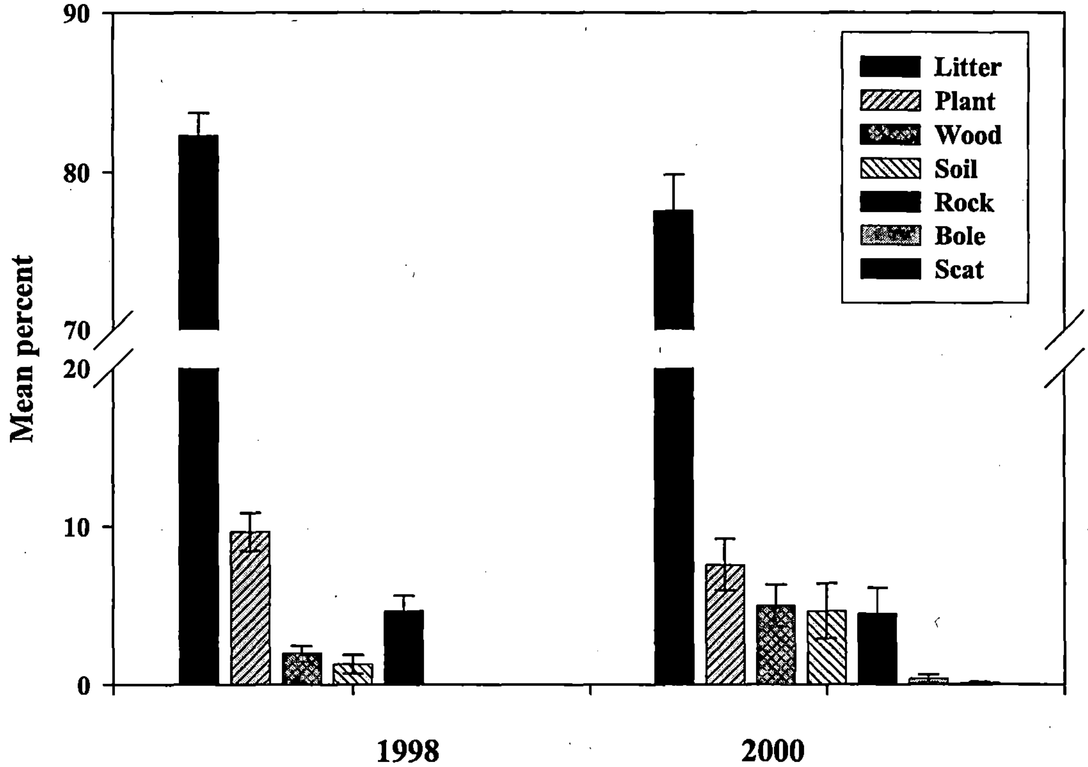


Figure 5. Substrate frequencies averaged over all plots at the Gila Mill site pre-treatment (1998) and post-treatment (2000).

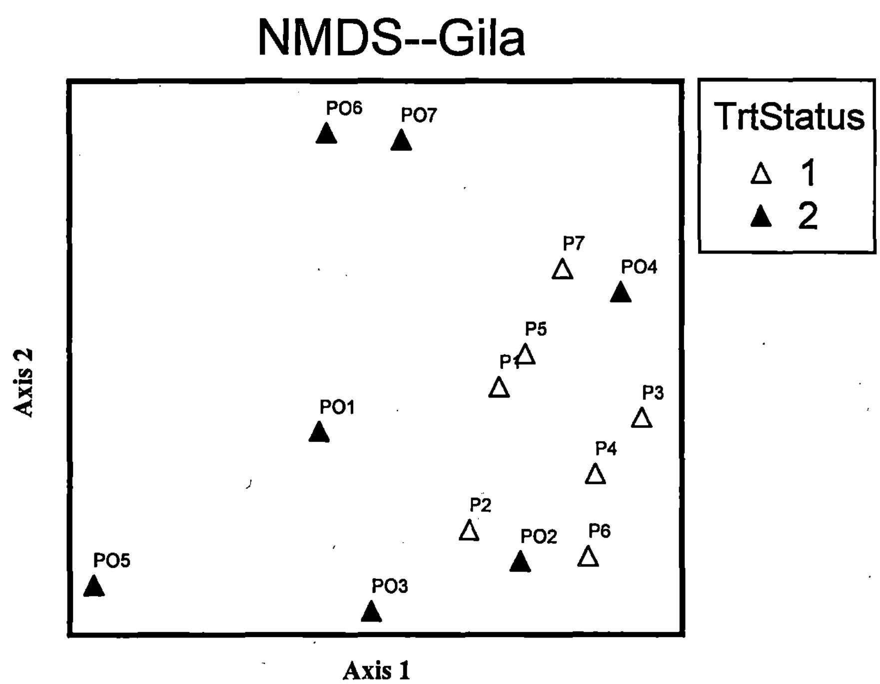


Figure 6. Ordination (NMDS) of pre-treatment (1998) and post-treatment (2000) data.

Appendix A. Comprehensive species list for Williams demonstration site.

Family	Species Name	Authority	Common Name	Duration	Nativity	Growth Habit	Code
Apiaceae	*Pseudocymopterus montanus*	(Gray) Coult. & Rose	alpine false springparsley	P	N	Forb	PSEMON
Asteraceae	*Achillea millefolium*	L.	common yarrow	P	N	Forb	ACHMIL
Asteraceae	*Agoseris sp.*		mountain dandelion	P	N	Forb	AGOS SP
Asteraceae	*Antennaria parvifolia*	Nutt.	smallleaf pussytoes	P	N	Forb	ANTPAR
Asteraceae	*Antennaria rosulata*	Rydb.	Kaibab pussytoes	P	N	Forb	ANTROS
Asteraceae	*Artemisia carruthii*	Wood ex Carruth.	Carruth's sagewort	P	N	Forb	ARTCAR
Asteraceae	*Bahia dissecta*	(Gray) Britt.	ragleaf bahia	B	N	Forb	BAHDIS
Asteraceae	*Cirsium sp.*		thistle	U	U	Forb	CIRS SP
Asteraceae	*Cirsium wheeleri*	(Gray) Petrak	Wheeler's thistle	P	N	Forb	CIRWHE
Asteraceae	*Ericameria nauseosa ssp. nauseosa var. nauseosa*	(Pallas ex. Pursh)	rubber rabbitbrush	P	N	Shrub	ERINAUN
Asteraceae	*Erigeron flagellaris*	Gray	trailing fleabane	B	N	Forb	ERIFLA
Asteraceae	*Erigeron sp.*		fleabane	P	U	Forb	ERIG SP
Asteraceae	*Heliomeris multiflora*	Nutt.	Showy goldeneye	P	N	Forb	HELMUL
Asteraceae	*Hieracium fendleri*	Schultz-Bip.	yellow hawkweed	P	N	Forb	HIEFEN
Asteraceae	*Hymenopappus filifolius*	Hook.	fineleaf hymenopappus	P	N	Forb	HYMFIL
Asteraceae	*Hymenopappus mexicanus*	Gray	Mexican woolywhite	P	N	Forb	HYMMEX
Asteraceae	*Hymenoxys bigelovii*	(Gray) Parker	Bigelow's rubberweed	P	N	Forb	HYMBIG
Asteraceae	*Hymenoxys richardsonii*	(Hook.) Cockerell	pingue hymenoxys	P	N	Forb	HYMRIC
Asteraceae	*Machaeranthera canescens*	(Pursh) Gray	hoary aster	P	N	Forb	MACCAN
Asteraceae	*Machaeranthera sp.*		hoary aster	P	N	Forb	MACH SP
Asteraceae	*Pseudognaphalium macounii*	(Greene) Kartesz. comb. nov. ined.	clammy cudweed	P	N	Forb	PSEMAC
Asteraceae	*Senecio multilobatus*	Torr. & Gray ex Gray	many-leaved gromwell	P	N	Forb	SENMUL
Asteraceae	*Senecio sp.*		gromwell	P	N	Forb	SENE SP
Asteraceae	*Solidago sp.*		goldenrod	P	N	Forb	SOLI SP
Asteraceae	*Taraxacum officinale*	G.H.Weber ex Wiggers	common dandelion	P	I	Forb	TAROFF
Asteraceae	*Townsendia exscapa*	(Richards.) Porter	stemless townsendia	P	N	Forb	TOWEXS
Asteraceae	*Tragopogon dubius*	Scop.	yellow salsify	AB	I	Forb	TRADUB
Boraginaceae	*Cryptantha sp.*		cryptantha	P	U	Forb	CRYP SP
Boraginaceae	*Lithospermum cobrense*	Greene	smooththroat gromwell	P	N	Forb	LITCOB
Brassicaceae	*Arabis sp.*		rockcress	U	U	Forb	ARAB SP
Brassicaceae	*Draba sp.*	L.	whitlowgrass	AB	N	Forb	DRAB SP
Brassicaceae	*Schoenocrambe linearifolia*	(Gray) Rollins	slimleaf plainsmustard	P	N	Forb	SCHLIN

Caryophyllaceae	*Arenaria sp.*		sandwort	P	U	Forb	AREN SP
Cyperaceae	*Carex occidentalis*	Bailey	western sedge	P	N	Graminoid	CAROCC
Cyperaceae	*Carex sp.*		upland sedge	P	N	Graminoid	CARE SP
Fabaceae	*Astragalus humistratus*	Gray	groundcover milkvetch	P	N	Forb	ASTHUM
Fabaceae	*Astragalus sp.*		milkvetch	P	N	Forb	ASTR SP
Fabaceae	*Lupinus argenteus*	Pursh	silver lupine	P	N	Forb	LUPARG
Fabaceae	*Lupinus kingii*	S. Wats.	Kings Lupine	A	N	Forb	LUPKIN
Fabaceae	*Medicago sp.*		alfalfa	U	U	Forb	MEDI SP
Fabaceae	*Robinia neomexicana*	Gray	New Mexico locust	P	N	Tree	ROBNEO
Fabaceae	*Vicia sp.*		vetch	P	N	Forb	VICI SP
Gentianaceae	*Frasera speciosa*	Dougl. ex Griseb.	showy frasera	P	N	Forb	FRASPE
Geraniaceae	*Geranium caespitosum*	James	pineywoods geranium	P	N	Forb	GERCAE
Geraniaceae	*Geranium sp.*		geranium	P	N	Forb	GERA SP
Pinaceae	*Pinus ponderosa*	P. & C. Lawson	ponderosa pine	P	N	Tree	PINPON
Poaceae	*Aristida arizonica*	Vasey	Arizona threeawn	P	N	Graminoid	ARIARI
Poaceae	*Blepharoneuron tricholepis*	(Torr.) Nash	pine-dropseed	P	N	Graminoid	BLETRI
Poaceae	*Bouteloua gracilis*	(Willd. ex Kunth) Lag. ex Griffiths	blue grama	P	N	Graminoid	BOUGRA
Poaceae	*Bromus tectorum*	L.	cheatgrass	A	I	Graminoid	BROTEC
Poaceae	*Dactylis glomerata*	L.	orchard grass	P	I	Graminoid	DACGLO
Poaceae	*Elymus elymoides ssp. elymoides*	(Raf.) Swezey	wildrye	P	N	Graminoid	ELYELYE
Poaceae	*Festuca arizonica*	Vasey	Arizona fescue	P	N	Graminoid	FESARI
Poaceae	*Lycurus phleoides*	Kunth	common wolfstail	P	N	Graminoid	LYCPHL
Poaceae	*Muhlenbergia montana*	(Nutt.) A.S. Hitchc.	mountain muhly	P	N	Graminoid	MUHMON
Poaceae	*Muhlenbergia sp.*	Schreb.	muhly	U	U	Graminoid	MUHL SP
Poaceae	*Muhlenbergia wrightii*	Vasey ex Coult.	spike muhly	P	N	Graminoid	MUHWRI
Poaceae	*Poa fendleriana*	(Steud.) Vasey	muttongrass	P	N	Graminoid	POAFEN
Poaceae	*Poa sp.*		bluegrass	P	U	Graminoid	POA SP
Poaceae	*Schizachyrium scoparium*	(Michx.) Nash	little bluestem	P	N	Graminoid	SCHSCO
Poaceae	*Sporobolus interruptus*	Vasey	black dropseed	P	N	Graminoid	SPOINT
Polemoniaceae	*Phlox gracilis*	(Hook.) Greene	slender phlox	A	N	Forb	PHLGRA
Polemoniaceae	*Phlox longifolia*	Nutt.	longleaf phlox	P	N	Forb	PHLLON
Polemoniaceae	*Phlox sp.*		phlox	P	U	Forb	PHLO SP
Polemoniaceae	*Phlox speciosa ssp. woodhousei*	(Torr. ex Gray) Wherry	Woodhouse's phlox	P	N	Forb	PHLSPEW
Polygonaceae	*Eriogonum alatum*	Torr.	winged buckwheat	P	N	Forb	ERIALA

Polygonaceae	*Eriogonum sp.*	Michx.	buckwheat	A	N	Forb	ERIO SP
Polygonaceae	*Polygonum douglasii*	Greene	Douglas' knotweed	A	N	Forb	POLDOU
Ranunculaceae	*Thalictrum fendleri*	Engelm. ex Gray	Fendler's meadowrue	P	N	Forb	THAFEN
Rhamnaceae	*Ceanothus fendleri*	Gray	Fendler's ceanothus	P	N	Shrub	CEAFEN
Rosaceae	*Potentilla crinita*	Gray	bearded cinquefoil	P	N	Forb	POTCRI
Rosaceae	*Potentilla hippiana*	Lehm.	woolly cinquefoil	P	N	Forb	POTHIP
Rosaceae	*Potentilla subviscosa*	Greene	Navajo cinquefoil	P	N	Forb	POTSUB
Scrophulariaceae	*Penstemon virgatus*	Gray	upright blue beardtongue	P	N	Forb	PENVIR
Scrophulariaceae	*Verbascum thapsus*	L.	common mullein	B	I	Forb	VERTHA

Appendix B. Comprehensive species list for Gila Mill Experimental Block Site.

Family	Species Name	Authority	Common Name	Duration	Nativity	Growth Habit	Code
Apiaceae	*Pseudocymopterus montanus*	(Gray) Coult. & Rose	alpine false springparsley	P	N	Forb	PSEMON
Asteraceae	*Achillea millefolium*	L.	common yarrow	P	N	Forb	ACHMIL
Asteraceae	*Achillea millefolium var. occidentalis*	(L.) D.C.	western yarrow	P	N	Forb	ACHMILO
Asteraceae	*Agoseris sp.*		mountain dandelion	P	N	Forb	AGOS SP
Asteraceae	*Antennaria parvifolia*	Nutt.	smallleaf pussytoes	P	N	Forb	ANTPAR
Asteraceae	*Antennaria sp.*		pussytoes	P	N	Forb	ANTE SP
Asteraceae	*Antennaria umbrinella*	Rydb.	umber pussytoes	P	N	Forb	ANTUMB
Asteraceae	*Artemisia carruthii*	Wood ex Carruth.	Carruth's sagewort	P	N	Forb	ARTCAR
Asteraceae	*Artemisia dracunculus*	L.	tarragon	P	N	Forb	ARTDRA
Asteraceae	*Artemisia ludoviciana*	(Nutt.) Keck	white sage	P	N	Forb	ARTLUD
Asteraceae	*Artemisia sp.*		sagewort	P	U	Forb	ARTE SP
Asteraceae	*Aster sp.*		aster	P	N	Forb	ASTE SP
Asteraceae	*Bahia dissecta*	(Gray) Britt.	ragleaf bahia	B	N	Forb	BAHDIS
Asteraceae	*Cirsium sp.*		thistle	U	U	Forb	CIRS SP
Asteraceae	*Erigeron divergens*	Torr. & Gray	spreading fleabane	B	N	Forb	ERIDIV
Asteraceae	*Erigeron flagellaris*	Gray	trailing fleabane	B	N	Forb	ERIFLA
Asteraceae	*Erigeron neomexicanus*	Gray	New Mexican fleabane	P	N	Forb	ERINEO
Asteraceae	*Erigeron speciosus*	(Lindl.) DC.	aspen fleabane	P	N	Forb	ERISPE
Asteraceae	*Gnaphalium exilifolium*	A. Nels	slender cudweed	A	N	Forb	GNAEXI
Asteraceae	*Gnaphalium sp.*		cudweed	P	N		GNAP SP

Asteraceae	*Grindelia aphanactis*	(Rydb.) Nesome	curlytop gumweed	P	U	Forb	GRIAPH
Asteraceae	*Hieracium fendleri*	Schultz-Bip.	yellow hawkweed	P	N	Forb	HIEFEN
Asteraceae	*Hymenopappus mexicanus*	Gray	Mexican woolywhite	P	N	Forb	HYMMEX
Asteraceae	*Laennecia schiedeana*	(Less.) Nesom	pineland marshtail	A	N	Forb	LAESCH
Asteraceae	*Pseudognaphalium macounii*	(Greene) Kartesz. comb. nov. ined.	clammy cudweed	P	N	Forb	PSEMAC
Asteraceae	*Pyrrhopappus pauciflorus*	(D. Don)DC.	small flower desert-chicory	AP	N	Forb	PYRPAU
Asteraceae	*Senecio actinella*	Greene	Flagstaff ragwort	P	N	Forb	SENACT
Asteraceae	*Senecio eremophilus*	Richards	desert ragwort	P	N	Forb	SENERE
Asteraceae	*Senecio multilobatus*	Torr. & Gray ex Gray	many-leaved gromwell	P	N	Forb	SENMUL
Asteraceae	*Senecio neomexicanus var. metcalfei*	Gray (Greene) T.M. Barkl	metcalf's groundsel	P	N	Forb	SENNEOM
Asteraceae	*Senecio sp.*		gromwell	P	N	Forb	SENE SP
Asteraceae	*Senecio werneriaefolius*	(Gray) W.A. Weber & A. Love	hoary groundsel	P	N	Forb	SENWER
Asteraceae	*Senecio wootonii*	Greene	Wooton's ragwort	P	N	Forb	SENWOO
Asteraceae	*Solidago canadensis*	L.	Canada goldenrod	P	N	Forb	SOLCAN
Asteraceae	*Solidago sp.*		goldenrod	P	N	Forb	SOLI SP
Asteraceae	*Taraxacum officinale*	G.H.Weber ex Wiggers	common dandelion	P	I	Forb	TAROFF
Asteraceae	*Townsendia exscapa*	(Richards.) Porter	stemless townsendia	P	N	Forb	TOWEXS
Boraginaceae	*Lithospermum multiflorum*	Torr. ex Gray	manyflowered gromwell	P	N	Forb	LITMUL
Boraginaceae	*Lithospermum sp.*		gromwell	P	N	Forb	LITH SP
Brassicaceae	*Thlaspi montanum*	L.	alpine pennycress	P	N	Forb	THLMON
Caryophyllaceae	*Arenaria sp.*		sandwort	P	U	Forb	AREN SP
Commelinaceae	*Commelina dianthifolia*	Delile	birdbill dayflower	P	N	Forb	COMDIA
Cupressaceae	*Juniperus deppeana*	Steud.	alligator juniper	P	N	Tree	JUNDEP
Cupressaceae	*Juniperus osteosperma*	(Torr.) Little	Utah juniper	P	N	Tree	JUNOST
Cyperaceae	*Carex geophila*	Mack.	White Mountain Sedge	P	N	Graminoid	CARGEO
Cyperaceae	*Carex occidentalis*	Bailey	western sedge	P	N	Graminoid	CAROCC
Cyperaceae	*Carex sp.*		upland sedge	P	N	Graminoid	CARE SP
Fabaceae	*Lathyrus sp.*		peavine	P	N	Forb	LATH SP
Fabaceae	*Lotus sp.*		birdsfoot trefoil	P	N	Forb	LOTU SP
Fabaceae	*Lotus wrightii*	(Gray) Greene	Wright's deervetch	P	N	Forb	LOTWRI
Fabaceae	*Lupinus neomexicanus*	Greene	New Mexico lupine	P	N	Forb	LUPNEO
Fabaceae	*Thermopsis divaricarpa*	A. Nels.	spreadfruit goldenbanner	P	N	Forb	THEDIV
Fabaceae	*Vicia ludoviciana*	Nutt.	Louisiana vetch	A	N	Forb	VICLUD

Fabaceae	*Vicia sp.*		vetch	P	N	Forb	VICI SP
Fabaceae	*Vicia villosa*	Roth	winter vetch	P	I	Forb	VICVIL
Fagaceae	*Quercus gambelii*	Nutt.	Gambel oak	P	N	Tree	QUEGAM
Fagaceae	*Quercus grisea*	Liebm.	gray oak	P	N	Shrub	QUEGRI
Fagaceae	*Quercus hypoleucoides*	A. Camus	silverleaf oak	P	N	Shrub	QUEHYP
Gentianaceae	*Frasera speciosa*	Dougl. ex Griseb.	showy frasera	P	N	Forb	FRASPE
Geraniaceae	*Geranium caespitosum*	James	pineywoods geranium	P	N	Forb	GERCAE
Geraniaceae	*Geranium sp.*		geranium	P	N	Forb	GERA SP
Lamiaceae	*Agastache sp.*		hyssop	P	U	Forb	AGAS SP
Lamiaceae	*Monarda sp.*	L.	beebalm	P	N		MONA SP
Lamiaceae	*Prunella vulgaris*	L.	common selfheal	P	N	Forb	PRUVUL
Malvaceae	*Sphaeralcea sp.*		globemallow	P	N	Forb	SPHA SP
Monotropaceae	*Pterospora andromedea*	Nutt.	woodland pinedrops	P	N	Forb	PTEAND
Orchidaceae	*Corallorrhiza maculata*	(Raf.) Raf.	summer coralroot	P	N	Forb	CORMAC
Orobanchaceae	*Conopholis alpina var. mexicana*		squawroot	P	N	Forb	CONALPM
Pinaceae	*Pinus ponderosa*	P. & C. Lawson	ponderosa pine	P	N	Tree	PINPON
Poaceae	*Bromus anomalus*	Rupr. ex Forn.	nodding brome	P	N	Graminoid	BROANO
Poaceae	*Bromus ciliatus*	L.	fringed brome	P	N	Graminoid	BROCIL
Poaceae	*Dactylis glomerata*	L.	orchard grass	P	I	Graminoid	DACGLO
Poaceae	*Elymus elymoides ssp. elymoides*	(Raf.) Swezey	wildrye	P	N	Graminoid	ELYELYE
Poaceae	*Festuca idahoensis*	Elmer	Idaho fescue	P	N	Graminoid	FESIDA
Poaceae	*Festuca ovina*	L.	sheep fescue	P	N	Graminoid	FESOVI
Poaceae	*Festuca sp.*		fescue	P	U	Graminoid	FEST SP
Poaceae	*Koeleria macrantha*	(Ledeb.) J.A. Schultes	prairie junegrass	P	N	Graminoid	KOEMAC
Poaceae	*Muhlenbergia longiligula*	A.S. Hitchc.	longtongue muhly	P	N	Graminoid	MUHLON
Poaceae	*Muhlenbergia virescens*	(Kunth) Kunth	screwleaf muhly	P	N	Graminoid	MUHVIR
Poaceae	*Poa ampla*	Merr.	Sandberg bluegrass]	P	N	Graminoi	POAAMP
Poaceae	*Poa fendleriana*	(Steud.) Vasey	muttongrass	P	N	Graminoid	POAFEN
Poaceae	*Poa pratensis*	L.	Kentucky bluegrass	P	I	Graminoid	POAPRA
Poaceae	*Sporobolus sp.*		dropseed	P	U	Graminoid	SPOR SP
Poaceae	*Vulpia octoflora*	(Walt.) Rydb.	sixweeks fescue	A	N	Graminoid	VULOCT
Polemoniaceae	*Ipomopsis aggregata*	(Pursh) V. Grant	skyrocket gilia	B	N	Forb	IPOAGG
Polygalaceae	*Polygala scoparioides*	Chod.	broom milkwort	P	N	Forb	POLSCO
Ranunculaceae	*Delphinium nuttallianum*	Pritz. ex Walp.	twolobe larkspur	P	N	Forb	DELNUT

Ranunculaceae	*Delphinium nuttallianum var. nuttallianum*	Pritz. ex Walp.	Nuttal's larkspur	P	N	Forb	DELNUTN
Ranunculaceae	*Delphinium sp.*			U	N	Forb	DELP SP
Ranunculaceae	*Thalictrum fendleri*	Engelm. ex Gray	Fendler's meadowrue	P	N	Forb	THAFEN
Rhamnaceae	*Ceanothus fendleri*	Gray	Fendler's ceanothus	P	N	Shrub	CEAFEN
Rosaceae	*Fragaria virginiana ssp. virginiana*	Duchesne	Virginia strawberry	P	N	Forb	FRAVIRV
Rosaceae	*Potentilla sp.*		cinquefoil	U	N	Forb	POTE SP
Rosaceae	*Potentilla thurberi*	Gray	scarlet cinquefoil	P	N	Forb	POTTHU
Rosaceae	*Prunus sp.*		cherry	P	U	Tree	PRUN SP
Rubiaceae	*Galium sp.*	L.	bedstraw	P	N	Forb	GALI SP
Rubiaceae	*Houstonia wrightii*	Gray	pygmy bluet	P	N	Forb	HOUWRI
Scrophulariaceae	*Castilleja sp.*		Indian paintbrush	P	N	Forb	CAST SP
Scrophulariaceae	*Penstemon sp.*		penstemon	P	N	Forb	PENS SP
Scrophulariaceae	*Penstemon virgatus*	Gray	upright blue beardtongue	P	N	Forb	PENVIR
Scrophulariaceae	*Verbascum thapsus*	L.	common mullein	B	I	Forb	VERTHA
Violaceae	*Viola canadensis*	L.	Canadian white violet	P	N	Forb	VIOCAN
Violaceae	*Viola sp.*	L.	violet	P	U	Forb	VIOL SP
Viscaceae	*Arceuthobium sp.*		mistletoe	P	N	Shrub	ARCE SP

Appendix C. Specimens collected at Williams demonstration site.

Family	Genus	Epithet	Variety	Date Collected	Herbarium	Coll. #	Plot
Apiaceae	***Pseudocymopterus***	***montanus***		18 May 1998	Deaver (ASC)	1621	WI-DEMO-3
	Location:	Williams Study Site, approx. 4.5mi SW of Parks, AZ					
Boraginaceae	***Cryptantha***	***sp.***		n.d.	NAU-ERI	1617	WI-DEMO
	Location:	Williams Study Site, approx. 4.5mi SW of Parks, AZ					
Poaceae	***Dactylis***	***glomerata***		18 May 1998	Deaver (ASC)	953	WI-DEMO-7
	Location:	Williams Study Site, 4.5 mi SW of Parks, AZ					
Poaceae	***Muhlenbergia***	***wrightii***		18 May 1998	NAU-ERI	952	WI-DEMO-5
	Location:	Williams Study Site, 4.5 mi SW of Parks, AZ					
Poaceae	***Muhlenbergia***	***wrightii***		19 May 1998	Deaver (ASC)	951	WI-DEMO-9
	Location:	Williams Study Site, 4.5 mi SW of Parks, AZ					
Poaceae	***Sporobolus***	***interruptus***		19 May 1998	NAU-ERI	1614	WI-DEMO-9
	Location:	Williams Study Site, approx. 4.5mi SW of Parks, AZ					
Polemoniaceae	***Phlox***	***gracilis***		18 May 1998	NAU-ERI	1628	WI-DEMO-3
	Location:	Williams Study Site, approx. 4.5mi SW of Parks, AZ					
Polemoniaceae	***Phlox***	***speciosa***	***ssp. woodhousei***	18 May 1998	NAU-ERI	1609	WI-DEMO-6
	Location:	Williams Study Site, approx. 4.5mi SW of Parks, AZ					
Polemoniaceae	***Phlox***	***speciosa***	***ssp. woodhousei***	19 May 1999	Deaver (ASC)	1608	WI-DEMO-9
	Location:	Williams Study Site, approx. 4.5mi SW of Parks, AZ					
Rosaceae	***Potentilla***	***subviscosa***		18 May 1998	NAU-ERI	1605	WI-DEMO-1
	Location:	Williams Study Site, approx. 4.5mi SW of Parks, AZ					

Appendix D. Specimens collected at Gila demonstration site.

Family	Genus	Epithet	Variety	Date	Herbarium	Coll. #	Plot
Asteraceae	***Antennaria***	***umbrinella***		2 Jun 1998	Deaver (ASC)	1296	GM-EB1-2
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Erigeron***	***divergens***		2 Jun 1998	NMC	1297	GM-EB1-2
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Erigeron***	***sp.***		3 Jun 1998	NAU-ERI	1298	GM-EB1-3
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Hieracium***	***fendleri***		3 Jun 1998	Deaver (ASC)	1263	GM-EB1-3
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Pyrrhopappus***	***pauciflorus***		21 Oct 1997	NAU-ERI	1892	GM-EB23-1
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Senecio***	***actinella***		3 Jun 1998	Deaver (ASC)	1262	GM-EB1-3
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Senecio***	***actinella***		3 Jul 1998	NMC	1891	GM-EB1-3
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Senecio***	***neomexicanus***	***var. metcalfei***	3 Jul 1998	NMC	1894	GM-EB1-1
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Senecio***	***neomexicanus***	***var. metcalfei***	2 Jul 1998	Deaver (ASC)	1893	GM-EB1-2
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Asteraceae	***Senecio***	***sp.***		3 Jun 1998	NAU-ERI	1290	GM-EB1-3
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Cyperaceae	***Carex***	***geophila***		9 May 2000	NMC	1903	GM-EB1-2
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					

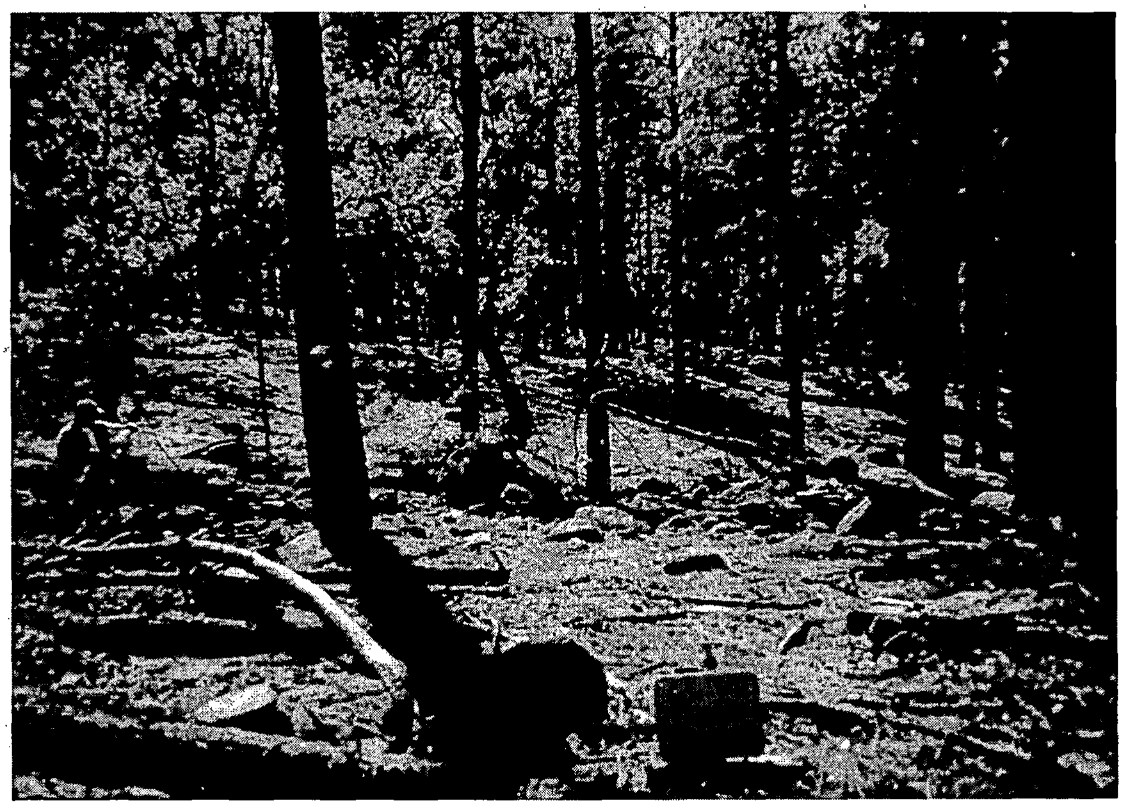
Family	Genus	Epithet	Variety	Date	Herbarium	Coll. #	Plot
Fabaceae	***Lupinus***	***neomexicanus***		4 Jun 1998	NMC	1287	GM-EB1-6
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Fabaceae	***Lupinus***	***neomexicanus***		2 Jun 1998	Deaver (ASC)	1288	GM-EB1-2
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Fabaceae	***Lupinus***	***neomexicanus***		2 Jun 1998	NAU-ERI	1289	GM-EB1-2
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Fabaceae	***Lupinus***	***neomexicanus***		9 May 2000	Exchange	1902	GM-EB1-1
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Fabaceae	***Phaseolus***	***sp.***		22 Oct 1997	NAU-ERI	1283	GM-EB-23-1
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Fabaceae	***Vicia***	***sp.***		10 May 2000	NAU-ERI	1905	GM-EB1-7
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Fabaceae	***Vicia***	***villosa***		10 May 2000	NAU-ERI	1904	GM-EB1-7
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Lamiaceae	***Prunella***	***vulgaris***		n.d.	Deaver (ASC)	1265	GM-EB23-1
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Orchidaceae	***Corallorrhiza***	***maculata***		3 Jun 1998	Deaver (ASC)	1261	GM-EB1-4
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Orobanchaceae	***Conopholis***	***alpina***	***var. mexicana***	10 May 2000	Deaver (ASC)	1906	GM-EB1-6
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Orobanchaceae	***Conopholis***	***alpina***	***var. mexicana***	10 May 2000	NMC	2101	GM-EB1-6
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Poaceae	***Bromus***	***anomalus***		22 Oct 1997	NMC	1901	GM-EB23-1
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					

Family	Genus	Epithet	Variety	Date	Herbarium	Coll. #	Plot
Poaceae	***Dactylis***	***glomerata***		9 May 2000	NAU-ERI	1917	GM-EB1-1
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Poaceae	***Festuca***	***idahoensis***		4 Jun 1998	Deaver (ASC)	1911	GM-EB1-5
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Poaceae	***Festuca***	***ovina***		9 May 2000	Deaver (ASC)	1913	GM-EB1-2
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Poaceae	***Muhlenbergia***	***longiligula***		21 Oct 1997	Deaver (ASC)	1900	GM-EB23-1
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Poaceae	***Muhlenbergia***	***virescens***		3 Jul 1998	Deaver (ASC)	1897	GM-EB1-3
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Poaceae	***Poa***	***ampla***		4 Jul 1998	Deaver (ASC)	1896	GM-EB1-7
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					
Poaceae	***Vulpia***	***octoflora***		2 Jul 1998	Deaver (ASC)	1895	GM-EB1-2
	Location:	New Mexico, Pinos Altos Range, Gila National Forest, Sheep Corral Canyon, north of Silver City					

Exhibit 1: SWFA Marking Guidelines for the Williams Site, June 9, 1998

Exhibit 2: Examples of Monitoring Plot Photographs

Williams Site, 1998 PRETREATMENT (Plot 8)



Gila Site, 1998 PRETREATMENT and 2000 POST-THINNING and POST-FIRE (Plot 5)